Resonance

July 1996 Volume 1 Number 7

journal of science education

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Challenges in Cosmology ❖ Knots
❖ A Tetrahedrane Derivative

Resonance is a monthly journal of science education published by Indian Academy of Sciences, Bangalore, India.

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Editorial

N Mukunda, Chief Editor

When we inaugurated ***Resonance*** in January 1996, our opening article was the first of a six-part series by Jayant Vishnu Narlikar titled "Origin(?) of the Universe." In the present issue he brings this well planned and beautifully structured series to an interesting and intriguing conclusion. He has covered the historical background of the subject starting from ancient times, and in successive stages taken readers through the discovery of the expanding universe, the big bang cosmology, nucleosynthesis, relic radiation, and the delicate problems of observation and interpretation in this challenging field. He (almost) started the series with a bang, and ends it now with a question, decidedly not a whimper. We would like to thank Narlikar for having so readily accepted our early invitation to him to contribute to ***Resonance***, and hope to see his writings again in these pages in future.

The general subject of biological rhythms has featured in several ***Resonance*** articles and news items. In this issue we present Erwin Bünning - the first chronicler of chronobiology - on the back cover. Also a delightful tongue-in-cheek article by Maroli Krishnayya Chandrashekaran on his days as a Ph.D. student at Madras in the early sixties, when he discovered the tidal rhythms of the mole crab. He tells us that in those days there was general skepticism world wide about biological rhythms, and that even his guide confided to him: "between you and me, I say, I don't really believe there are rhythms." Now you seem to find them all over the biological world, but not, as Chandrashekaran says, if you work 9 to 5!

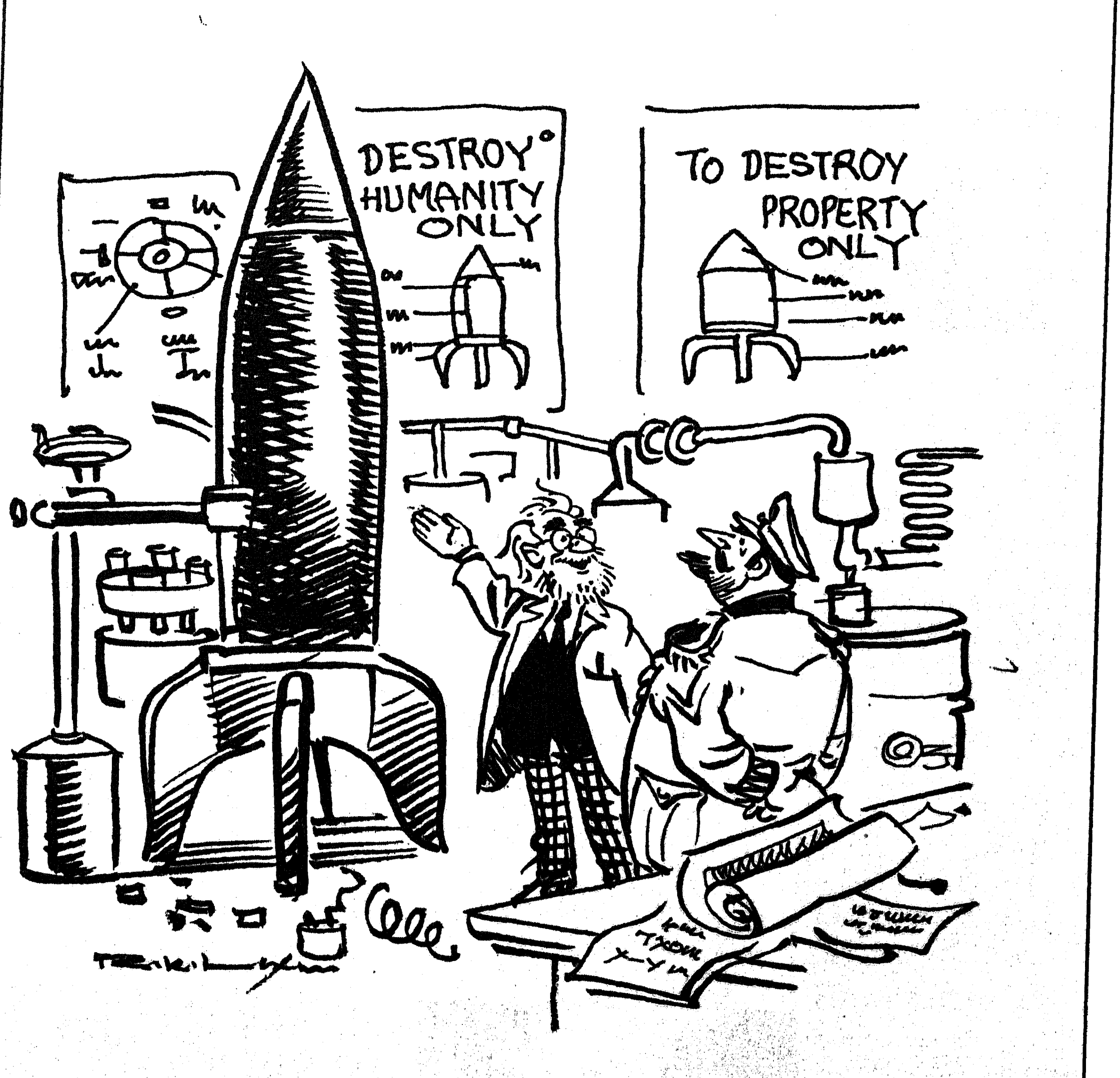
V Shankar Sunder contributes an article on the mathematical problems of knots and their properties. In common with Pati's piece on "The Punctured Plane" a few months ago, this may be

slightly demanding, but also rewarding for an interested reader with a mathematical bent of mind willing to work a little bit and appreciate new ideas. If you end up feeling tied up in knots - dont worry, Sunder's formulae will help you come untied as well!

Finally, our Reflections section carries this time the complete text of a lecture on "Science - its Philosophy and Spirit" given a few months ago under the auspices of the Indian Academy of Sciences by Professor Sir Herman Bondi, who occupied the Raman Chair at the Academy during December 1995 - February 1996. Bondi is very well known in the physics and astronomy community, and well beyond, for his pioneering work with Thomas Gold and Fred Hoyle on the steady state model of the universe almost a half century ago; and equally for his razor-like sharpness and clarity of expression in lectures and writings. Here he dwells on some general questions of the philosophy of science, the relationship between science and technology, the problems of communication and teaching - all interspersed with witty comments and anecdotes. He explains why he follows the Popperian approach to science - the scientific value of a statement consists in the possibility of its being tested and disproved. "I tell you something valuable only if I may turn out to be wrong." And the image of the person walking in a swamp-with one leg labelled science and the other technology - illustrates in an unforgettable way how interdependent they are. Bondi also carefully explains how Popperian criteria remain valid in those sciences which have a historical character and are not subject to repeatable experiments. He stresses the self-correcting character of science, and students and teachers alike will find his remarks on research and communication "so serious that you can only joke about them."

Science Smiles

R K Laxman



As a humanitarian, in this I have combined the qualities of preserving the people as well as their property

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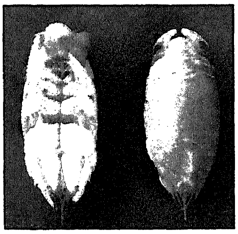

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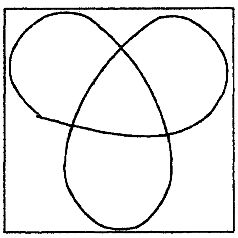

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Memory	Register
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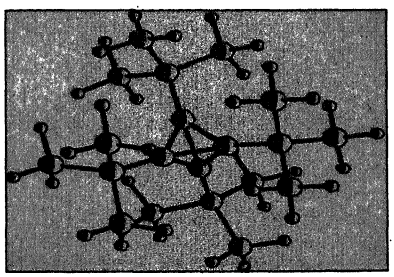

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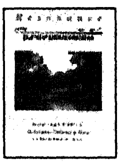


Front Cover

A herd of Sambar quench their thirst at a water hole early in the morning in Sariska Tiger Reserve, Rajasthan. On the right are two males, one in hard antler and one that has just shed its antlers. Females and a large fawn are also visible (Photograph by T R Shankar Raman).

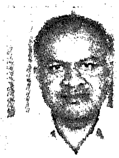
Back Cover

Erwin Bünning (1906 - 1990)
Illustration by Prema Iyer

Origin(?) of the Universe

6. Present Challenges in Cosmology

Jayant V Narlikar



Jayant V Narlikar, Director, Inter-University Centre for Astronomy and Astrophysics, works on action at a distance in physics, new theories of gravitation and new models of the universe. He has made strong efforts to promote teaching and research in astronomy in the universities and also writes extensively in English and Marathi for a wider audience on science and other topics.

This six-part series will cover: 1. Historical Background. 2. The Expanding Universe. 3. The Big Bang. 4. The First Three Minutes. 5. Observational Cosmology. 6. Present Challenges in Cosmology.

The final article in the series reviews the strengths and weaknesses of the big bang cosmology, conceptual as well as observational. It is argued that despite its many successes there are enough question marks against this cosmology to keep the issue open. In particular, an alternative view-point developed by the author and his colleagues is described. In this the universe has always been in existence. Known as the Quasi-Steady State Cosmology it combines some good features of the big bang cosmology with new ideas which may help resolve some of the outstanding questions of today.

Strengths and Conceptual Weaknesses of the Big Bang Cosmology

In this concluding part of the series on cosmology we shall take a critical look at the big bang models and then make some projections for the future. To begin with, we consider the strengths of these models. Recall from Part 3 of the series that Einstein's general theory of relativity led Alexander Friedmann to expanding world models in 1922, and seven years later Hubble's law that received a simple interpretation within the Friedmann models was discovered.

Then in the 1940s, extrapolation of these models to epochs very close to the Big Bang led George Gamow and his students Ralph Alpher and Robert Hermann to the concept of primordial nucleosynthesis. And from their considerations of the early universe emerged the idea of a present day background of isotropic radiation. Both these concepts of relic

nuclei and relic radiation received observational backing in the 1960s and 1970s through the measured abundances of light nuclei (^{4}He, ^{2}H, etc.) and the microwave background (see Part 4 of the series).

These are then the plus points of the big bang picture entitling it to a prima-facie position of trust. In any emerging branch of science such a theory is needed at the beginning. But after the early stages are completed and the subject progresses, one must take a more critical look at the theory, to see how far it fits the more detailed experiments / observations that inevitably follow. When we carry out such an exercise for the standard hot big bang cosmology, several disquieting features begin to show up.

Singularity : The concept of big bang origin itself marks a departure from standard physics. The event cannot be described by standard techniques of theoretical physics : all the equations break down. Mathematicians would call this a *singular* event, i.e., one where no standard mathematical techniques work. To the physicist, the appearance of *all* the matter in the universe at $t > 0$ with no discussion of what went on at $t = 0$, violates its conservation laws.

There are many plus points of the big bang picture entitling it to a prima-facie position of trust. But, a critical look reveals several disquieting features.

Some big bang cosmologists regard this as the signature of the profundity of the *Big Bang*. They argue that this event marks the origin of the universe including the origin of science and its laws; as such it lies beyond the scope of science. Other cosmologists regard this as a sign of incompleteness of our present understanding of science : perhaps the singularity would 'go away' when we learn more mature physical laws than we now know (e.g., quantum gravity).

Inflation : Approach of the latter kind led in the 1980s to the now well known idea of the *inflationary universe*. D Kazanas, K Sato and A Guth during 1980-81 independently suggested this idea. It takes into consideration the so-called grand unified

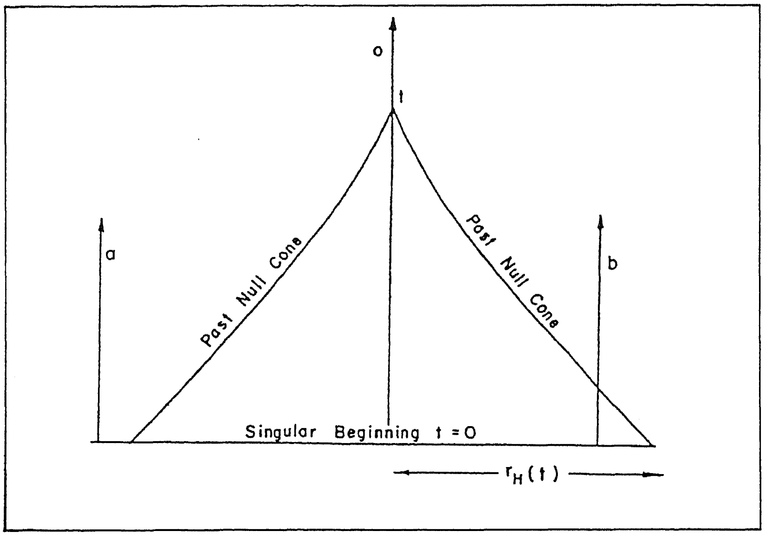


Figure 1 The Horizon Effect. The past light cone of observer O at r = 0, epoch t, terminates at the big bang epoch t = 0. There it has a radial coordinate extent of r_H (say). Particles like a lying beyond this distance don't causally affect the observer at O while particles like b lying within this cone do. The limited value of r_H for small t places a severe limit on the extent to which the universe can be homogeneous.

theories (GUTs : see Part 4 of the series) which seek to unify all laws of physics into one single comprehensive framework. Particle physicists believe that GUTs will be significantly effective for very high energy particles, such as those found shortly after the big bang. Typically, GUT-energies are of the order of 10^{16} GeV per particle (1 GeV approximately equals the energy store of a proton) and such energies per particle may arise about 10^{-36} second after the big bang.

Just as a temperature of 100 Celsius marks a change of state for water to steam or vice versa, so does this energy mark a phase transition for the universe in the inflationary theory. As the universe expands it 'cools' with the particle energies dropping continuously. At $\sim 10^{15}$- 10^{16} GeV, the GUTs suggest a change of the lowest energy state of matter, normally designated as 'vacuum' in quantum theory. The universe discovers that extra energy is suddenly available for it to expand very rapidly. This same extra energy of steam condensing to water appears as latent heat.

This rapid expansion is called *inflation*. Just as compound interest grows much faster than simple interest, an inflationary universe expands very rapidly. This rapid

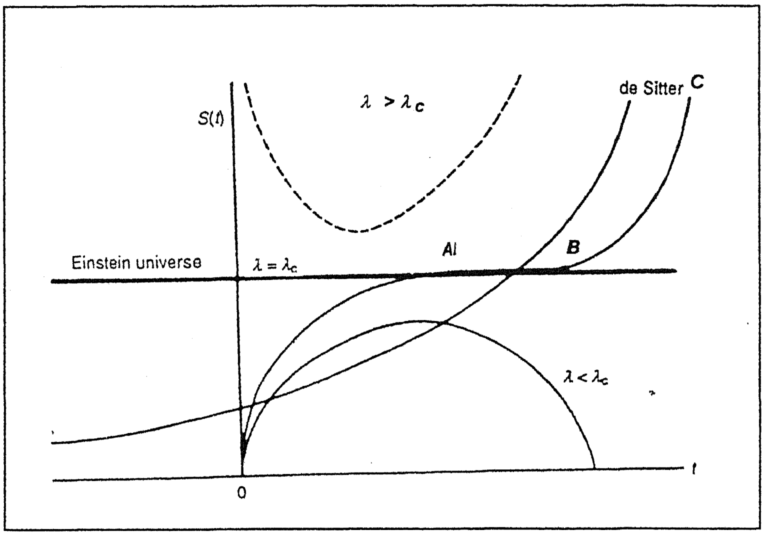


Figure 2 The scale factors of some of the different types of models with a non-zero cosmological constant are shown. In a typical model, by choosing λ close to the critical value λ_c, we can have a universe which expands from O to A, stays nearly static over an arbitrarily long stretch from A to B and then expands from B to the present C. Note that over the stretch BC the Universal expansion tends to accelerate. The figure also shows the 1917 models of Einstein and deSitter.

expansion lasts a very short time but is enough to make the initial size larger by a factor as high as 10^{50}.

Rapid expansion of this kind produces some lasting effects in the universe. One is that it helps to make it more homogeneous. Imagine a typical region 10^{-36} second after the big bang. Any physical effect will travel in it at most with the speed of light, $c = 3 \times 10^{10}$ cm/s and so will not cover a distance of more than 3×10^{-26} cm. Normally therefore we would expect regions of this size to be 'homogenized' at 10^{-36}s. Had there been no inflation, the normal slower expansion would have further increased their size at most to $\sim$ 10 cm to 1 metre at the present epoch.

Known as the *horizon effect*, this had been a ticklish problem for the standard Friedmann models. Why do we find the universe homogeneous on scales of $\sim 10^{26}$ metres when it should have been so only on scales of at the most 1 metre? The problem disappears if we assume the inflationary phase in between.

The inflationary phase also *flattens* the universe, that is, it severely diminishes the effect of the curvature term k / S^2 in

the expansion of the universe (see Parts 3 and 4 of the series). Thus it strongly predicts that the present universe should be almost indistinguishable from the flat ($k = 0$) case.

An added advantage of the inflationary model is the way it allows any initial (primordial) inhomogeneities in the universe to grow. It predicts a spectrum of inhomogeneities which does not depend on scale. The present studies of large scale structure from galaxies to superclusters substantiate this prediction.

In spite of these attractive features the inflationary models also have their own conceptual problems. There have been several detailed inflationary models based on speculations in high energy particle physics, but they seem contrived and fine-tuned to get specific results.

The now well known idea of the *inflationary universe* was born in the 1980's to handle the *singularity problem*.

Some Practical Weaknesses of Big Bang Cosmology

Let us now look at a few of the problems that the big bang cosmology is currently facing.

The age problem : We referred to it in the last part of this series. If we accept the inflationary big bang model and the current estimates of Hubble's constant then the age of the universe is no greater than 8–10 billion years. This is far too short to accommodate galactic and stellar ages in the range of 12–18 billion years.

If we assume that all these values are correct, how does the big bang concept survive? Recall that in Part 3 of the series we had referred to the cosmological constant λ, first introduced by Einstein, then discarded as unnecessary but still available to the theoretician if needed as an extra parameter. Faced with the above problem, some theoreticians are once again taking refuge behind the cosmological constant.

In the inflationary model the cosmological constant is explained as the feedback of vacuum forces on spacetime. The inflationary expansion is caused by these forces. Conventionally these forces disappear when the GUTs phase transition is over and so today there is no λ – force around. But suppose that λ did not disappear entirely but a fraction, a few parts in 10^{108}, did survive. Then we would have a considerably reduced but nevertheless significant λ –term available today. And by a suitable choice of λ we may increase the theoretical age of the big bang model to around 15 billion years.

Over the last few years several inadequacies of big bang models are being increasingly noticed. Some cosmologists feel that one can play with available parameters and make the models work.

Opinions differ amongst cosmologists as to whether this is the correct way out. At best the above explanation is contrived and may be termed as a "refuge for scoundrels!" At worst it still fails because it requires the expansion of the universe to accelerate at present and all observed indications are to the contrary.

The structure formation constraint : The inflationary cosmology provides a rationale for the scales of different structures. But detailed theories of structure formation must take into consideration the following questions :

- How do large scale structures grow by mutual gravitational interaction?
- How does the expansion of the universe control the growth?
- In what way do inhomogeneities arise in the form of long chains of galaxies with large voids in between ?
- What is their feedback on the observed inhomogeneities of the cosmic microwave background?
- How does non-baryonic dark matter affect structure formation?
- How and why do we find large scale streaming motions of galaxies as large as 1000 km/s over and above the Hubble expansion?

Alternatives to the standard big bang cosmology have been in the field from time to time. The most significant of them was the steady state cosmology proposed in 1948 by Hermann Bondi, Thomas Gold and Fred Hoyle.

Despite the euphoria of 1992 when COBE discovered, for the first time, tiny inhomogeneities of temperature (a few parts in a million) of the microwave background, and even after several different approaches to forming large scale structures, the gap between theories and observations remains wide. Maybe the gap will be eventually bridged but again only at the cost of elegance.

The Quasi-Steady State Cosmology

Over the last few years these inadequacies of big bang models are being increasingly noticed. Some cosmologists feel that one can play with available parameters (add a few more if needed) and make the models work. This attitude coupled with attempted scenarios is beginning to resemble epicyclic theories of the ancient Greeks trying to fit the observed planetary motions within the Aristotelian framework. While the majority of cosmologists have taken the neutral stance of waiting and watching as the situation develops, a few have taken the bold steps of suggesting alternatives.

Alternatives to the standard big bang cosmology have been in the field from time to time. The most significant of them was the steady state cosmology proposed in 1948 by Hermann Bondi, Thomas Gold and Fred Hoyle. This cosmology has the universe in perpetual existence with new matter being

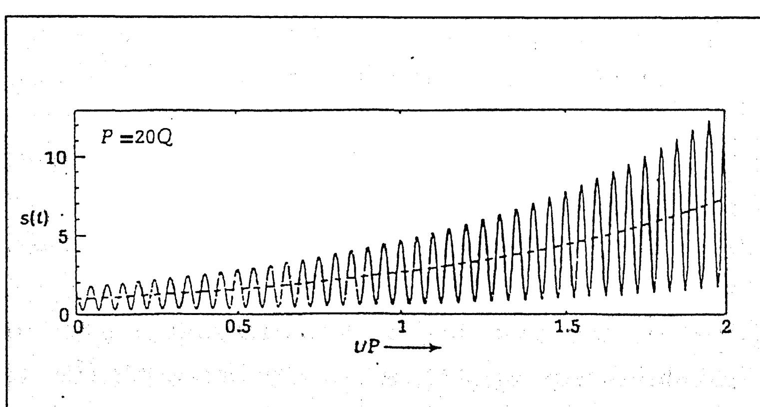


***Figure 3** The Quasi-Steady State Cosmology shows expansion over a long time scale with cycles of expansion and contraction. This universe did not have any finite epoch of origin but has been in existence perpetually.*

injected into it steadily. The stresses produced by the injection process keep the universe in steady expansion with a scale factor $S\ (t) = \exp\ (Ht)$. This model has a constant Hubble's constant. Indeed, as the adjective 'steady' implies, all its physical characteristics are epoch-independent.

The steady state model fell into disfavour because it could not offer a reasonable explanation for light nuclear abundances and the microwave background.

This alternative played a useful role for nearly two decades by prompting observers to find tests to distinguish between it and the big bang cosmologies. As discussed in Part 5 of the series most such tests turned out to be indecisive but they led to an improvement of extragalactic astronomy. Eventually however, the steady state model fell into disfavour because it could not offer a reasonable explanation for light nuclear abundances and the microwave background.

Since 1992, however, Fred Hoyle, Geoffrey Burbidge and this author have revived the steady state idea in a more realistic form. Called the *Quasi-Steady State Cosmology* (QSSC), this model has a scale factor given by

$$S\ (t) = \exp\ (t/P)\ .\ [1 + \alpha \cos \theta\ (t)].$$

Here the exponential function is the steady state part with a time scale P. The function $\cos \theta\ (t)$ is periodic but has a much shorter time period Q, while α is a parameter lying between 0 and 1. The periodic part is the reason for the adjective quasi-steady. The universe has no beginning and has a long term exponential trend of expansion superposed on short term oscillations.

What is the physical cause of such dynamical behaviour? The QSSC has a field theory for matter creation which allows for matter to be created near collapsed massive objects. The process conserves energy. Thus a negative energy field is produced along with matter and with its large negative stresses the field drives the matter out explosively.

In 1992, Fred Hoyle Geoffrey Burbidge and this author revived the steady state idea in a more realistic form, and called it *Quasi-Steady State Cosmology* (QSSC).

So, instead of a mythical primordial event of Big Bang, we have here minicreation events (MCEs) whose explosive character can be described by a respectable field theory. Also the Big Bang has not been observed (nor is it observable) but the MCEs are, in this picture familiar to us in the form of explosions in galactic nuclei. *Thus while every particle of matter has a finite beginning the universe as a whole has had no origin.*

A comparison with observations suggests that $P \sim 10^{12}$ years, $Q \sim$ 40–50 billion years while $\alpha \sim 0.8$. Thus these time scales are large compared to the big bang time scales. Although they are consistent with Hubble's constant as measured today, *there is no age problem*. But how does this cosmology explain the microwave background?

Recall that the time scale Q of a typical cycle of QSSC is long enough to burn out all but the very low mass stars. The light of stars from all previous cycles is left over in the universe. If it can somehow be thermalized we should get the *exact* microwave background of temperature 2.7 kelvin. Hoyle et al show that 0.5-1 mm long whiskers of iron could carry out this thermalization efficiently. Laboratory evidence shows that hot metallic vapours condense as whiskers just like these. Thus iron produced and ejected from supernovae can indeed condense as metallic whiskers. These whiskers are pushed out into intergalactic space where they efficiently thermalize the relic starlight.

In QSSC, the universe has no begining and has a long term exponential trend of expansion superposed on short term oscillations.

What happens to the burnt out stars? These appear as dark matter. The dark matter in the QSSC thus appears to be largely baryonic. Note that the baryonic option for dark matter is denied to the big bang cosmology as it severely cuts down the production of deuterium in primordial nucleosynthesis (see Part 5 of the series). The production of light nuclei in the QSSC follows an entirely different route

that is unaffected by the baryonic density in the universe. What is that route?

In the QSSC the primary particle created has the Planck mass

$$m_P = \sqrt{c\hbar / G}$$

which is about 10^{-5} gram. This particle is short lived and decays into baryons of high energy. The particle theory of baryons tells us that these are distributed in octets of which only two, the neutron and the proton survive. These form helium nuclei while the remaining six decay to protons, i.e., hydrogen nuclei. Thus the mass abundance of helium is nearly 25%. More accurate calculation reduces this to between 22% to 23% while producing other light nuclei like deuterium, lithium etc. and some metals.

To Sum Up

Thus the QSSC provides, prima facie, viable scenarios for the present observed features of the universe. Yet it differs radically from the hot big bang scenario. Can we distinguish between the two theories by suitable tests?

Notice that the QSSC has contracting as well as expanding phases of the universe. So there is a possibility of detecting faint *blue-shifted* galaxies. Then, the QSSC predicts the dark matter to be largely baryonic, being made of stellar remnants. It also predicts the existence of stars of low mass (half the Sun's mass) from the previous cycle that are just about branching off as red giants. Such stars would be 40-50 billion years old.

None of these possibilities are allowed by the standard hot big bang cosmology. And so here are ways of distinguishing between the two cosmologies. Only then will we be able to assert whether the universe had a definite origin or whether it has been going on for ever.

Suggested Reading

J V Narlikar. The Primeval Universe. Oxford University Press. 1989.

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John Barrow. The Origin of the Universe. Weidenfield & Nicolson, London. 1994.

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Know Your Personal Computer

4. The CPU Base-Architecture

S K Ghoshal

This article surveys the CPU chips of the IBM Personal Computer using the Intel 80X86 family as the base.

Siddhartha Kumar Ghoshal works with whatever goes on inside parallel computers. That includes hardware, system software, algorithms and applications. From his early childhood he has designed and built electronic gadgets. One of the most recent ones is a sixteen processor parallel computer with IBM PC motherboards.

Introduction

Intel 80X86 CPUs are used in the IBM PC. 80X86 means all CPUs in the family - (or should we call it a dynasty?) - the 8086 (and that includes its shorter external data-bus width cousin 8088), 80186 (and its cousin 80188), 80286, 80386 (and its cousin 80386 SX), 80486 (including the cousin 80486 SX) and the Pentium. Each does what its predecessor did. It does them faster and adds some more capabilities. This is called *upward compatibility*. The cousins are cheaper although slower and it is easier to build motherboards with them. We will first discuss the base architecture that runs across the dynasty. 80X86 is a complex instruction set CPU (CISC CPU).

Each 80X86 instruction typically has two operands, *source* and *destination*, even though the destination operand initially contains one of the inputs to the operation. The format of an instruction is 'Operation-name *destination*, *source*'. The instruction operates on the operands and then overwrites the *destination* operand with the result. As an example, the instruction 'XOR AX, BX' performs an exclusive-OR of the contents of the CPU registers whose names are AX and BX and overwrites AX with the result. The 80X86 allows all types of instructions except those in which both operands are in memory, as shown in the margin.

Destination	Source
Register	Register
Register	Immediate
Register	Memory
Memory	Register
Memory	Immediate

There are 14 registers in the 8086: Eight general-purpose

CISC and RISC

CISC and RISC are terms that classify CPUs into two categories subjectively. The terms RISC (reduced instruction set computer) and CISC (complex instruction set computer) are misnomers because they refer to the CPU. CISC CPUs allow many ways to get at an operand that resides in memory. RISC CPUs allow only move-operations between a memory location and a CPU register. CISC instructions can have a variable length. RISC instructions always have a fixed length. CISC instructions can take a variable amount of time to complete execution. All RISC instructions take the same amount of time. Some CISC instructions can be very powerful. All RISC instructions have the same strength. Instructions occur in a stream and the stream is compiled from a high-level language source code. All CPUs execute or at least try to execute more than one instruction from the stream simultaneously. This is known as *pipelining*. RISC CPUs allow better coordination among instructions in the *pipeline* and this results in better sharing of different resources within the CPU. That is because the compiler can predict which instruction will need which resource, at what stage of its execution and for how long. So RISC CPUs yield better performance. RISC is the modern trend of CPU design. There are many vendors who brand their CPUs as RISCs, whereas actually they are not. Also, the intelligent reader may note that just a CPU being an RISC does not guarantee better performance on a given application. It depends on how the high-level language code is compiled to take advantage of the CPU architecture. Thus CISCs can be exploited by executing their powerful instructions and that may outperform an RISC at times. There is no reason for a vendor to feel defensive about her CPU being a CISC.

16-bit registers, (name given by Intel) four 16-bit segment registers (name given by Intel) and the two program control registers (name given by me).

The eight 16-bit registers, (*viz.* AX, BX, CX, DX, SP, BP, SI and DI) hardly justify the name *general purpose registers* (GPRs). Each register has a specific use. It is recommended that one keep certain types of operands in certain registers. The experienced assembly language programmer knows by instinct which register to use to keep what operand but it is unfair to expect a compiler to be endowed with such an 'instinct'. And what is worse, some instructions must use some specific registers as their destination and you must leave the register free before you try to execute the instruction.

Figure 1 General - purpose registers of the 8088 CPU

AH	AL	AX (Accumulator)
BH	BL	BX (Base)
CH	CL	CX (Count)
DH	DL	DX (Data)
15	8 7	

Of the eight GPRs, four are better at handling data. They are AX, BX, CX and DX. Each of them can be seen either as two 8-bit registers (e.g. AH and AL) joined end to end or as one 16-bit register (e.g. AX). The 8-bit registers were there in the 8-bit 8085 (Figure 1).

Even among the data registers, there are 'specialists'. AX is good at collecting the results of arithmetic and logic operations. It is very strongly tied to the ALU (arithmetic and logic unit) and can serve as the source and destination of instructions that use the ALU. Thus when you operate on a program variable over and over, AX can be used to hold the variable during the long chain of instructions being executed and accumulate the end result. So AX is called the *accumulator*. BX is a specialist of

How the Intel 8088 Registers Got their Names

The predecessor of the Intel 8088 microprocessor (the first CPU of the IBM PC) was the highly successful 8085 microprocessor from Intel which had a data word length of 8 bits and which could address 216 bytes of memory (i.e. it had a 64KB long virtual address space). The 8088 had 16-bit wide internal data paths and registers. However to reduce the pin count of the chip, the external data path width of the 8088 chip was kept at eight. By then, the 8085 had featured in a sufficient number of single-board computers to bolster the confidence of a board-level computer designer to be able to use a CPU that (like the 8085) also had a data-width of 8 bits, in the single-board computer. Internal to the die, the 8088 had 16-bit registers that were extensions of the corresponding 8-bit registers of the 8085 (See *Figure 1*). All the registers with an 'L' as the last alphabet of their name are 8-bit registers which were there in the 8085. They were extended with another 8-bit register with an 'H' as the last alphabet of their name, to make a 16-bit register with an 'X' as the last alphabet of their name. The two 8-bit registers can be address- ed either separately or together as a 16-bit register.

memory address arithmetic. Scaling of offsets and indexing into a block of memory is better done using BX to hold the base address. Some programmers call it the base register. CX is good at keeping count of operations. Loop instructions are designed by the CPU architect to use CX as the count register. CL keeps count of things that can be done sensibly only up to a maximum of 255 times. For example, CL counts the number of shifts and rotate operations done on other registers holding bit-patterns. DX points at addresses of Input/Output ports, peripheral controller devices, their control registers and the like. I do not know why it is called the data register. May be because eventually all data get in or get out through Input/Output devices.

SP	(Stack Pointer)
BP	(Base Pointer)
SI	(Source Index)
DI	(Destination Index)

Figure 2 Pointer and Index registers of the 8088

There are four GPRs belonging to the pointer and index group. They are 16-bit long and none of them can be used as two 8-bit registers joined end to end. (See *Figure 2*). These are good at pointing at objects in memory and they increment and decrement fast. SI (source index) and DI (destination index) are specialists in holding the addresses of the source and the destination operands respectively. They come in handy for string operations when they increment and decrement automatically after each byte is moved while CX keeps the count. Thus large blocks of memory can be scanned, copied and initialized very fast just by writing one string instruction. This is one example of the power of a CISC architecture.

What is an Immediate Operand?

When the value of an operand is encoded within the instruction it is called an immediate operand as its value is known as soon as the instruction is decoded. For example, the instruction MOV AX, 0FFFFH is encoded in three consecutive bytes (each byte needs two hexadecimal digits to store) as B8FFFF. The byte B8 is the op-code of the move instruction. FFFF is the immediate operand of the same instruction.

The stack pointer, SP points to the top of the stack. When any object is pushed, it decrements by an amount that equals the size of the object in bytes. When an object is popped, SP increments. The careful reader will note that SP is a highly special-purpose register, even though it is branded as a GPR. You cannot write any useful program that uses SP to do anything other than point at the last object pushed into the stack. BP too is a specialist in pointing at objects in the stack. It follows SP whenever any subprogram is called and serves as a base pointer from which the parameters passed to the subprogram can be accessed easily.

Code, Data and Stack

To support a program in execution (some call a prog- ram in execution as a process), one needs to logically subdivide memory into three different regions:

Code region from where the CPU fetches, decodes and executes instructions,

Data region where variables used in a program are stored,

Stack region where the CPU temporarily stores addresses of instruction so that a program can call subprograms or invoke operating system calls. The stack is organized in such a way that the last item pushed onto the stack is the first item to be taken off (*popped*) and hence the name, as in a stack of cafeteria trays mounted on a dispenser. Stack is also used to pass values (called *parameters*) to subprograms.

In a flat memory model code, data and stack regions are all squeezed into one common virtual address space and can overrun each other if the program misbehaves, causing havoc that can result in a system crash. On a CPU that supports segmentation, a misbehaving program cannot cause as much damage. A region is recognized and protected by the CPU as part of its architectural responsibilities.

Using BP, one can also quickly pick out local variables allocated to a subprogram, and other temporary objects created on stack during the execution of the subprogram. This is very useful in supporting the execution of subprograms that call themselves.

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Data can be moved between any of these registers over paths that are 16-bit wide and run internal to the CPU. The 8088 has only a 8-bit wide data path that comes out of the CPU. That makes motherboards made out of the 8088 a whole lot cheaper, rugged and reliable. The CPU-memory subsystem of an 8088-based motherboard works a bit slower though, compared to an equivalent 8086-based motherboard.

Suggested Reading

Peter Norton and John Socha, Peter Norton's Assembly Language Programming Book for the IBM PC, Prentice Hall of India. 1989.

Patterson and Hennessy, Computer Architecture - A Quantitative Approach, Morgan Kaufmann. 1990.

Earlier 8-bit board level products were common. Thus the 8088 having an eight bit external data path width certainly helped in making 8088-based motherboards acceptable among people who wanted their board-level products to interface with the IBM PC. These people pioneered to make the IBM PC the most diversely interfaced computer of the world.

There are two 16-bit program control registers IP and FLAGS. These registers are not meant for storing data. Their contents

The SX Idea

Even today the trend, where the width of the external data-path is half that of the internal data-path and operand size of the CPU, is continued by some designers. At Intel, such a CPU is called an SX CPU, whereas the regular one, whose external data-path is as wide as the internal data-path, is called a DX CPU. It is an unwise name given by Intel, as there is a register called DX within the CPU. For example, the 80386 is a 32-bit CPU. It has internal data-paths and registers that are 32 bits wide. The 80386 DX has 32 data pins to exchange information with its main memory. The 80386 SX has 16 data pins. Motherboards with SX CPUs (referred hereafter as SX motherboards) are more easily designed than motherboards with DX CPUs (referred hereafter as DX motherboards). This is because there are fewer wires that run between the CPU and the memory. They cost much less than DX motherboards and perform only slightly worse in the majority of applications. SX motherboards are more rugged, smaller in size and consume less electrical energy than DX motherboards.

affect the way the CPU executes instructions. The programmer should not try to load values into these registers, though there are ways of doing it. Depending on the result of executing an instruction, the contents of these two registers are set by the CPU automatically. Thus these two registers are a very important

Keep the Pin-count Low

Another challenge those days was to package the silicon chip (also called a "die") inside a 40-pin Dual In-line Package (DIP). The total number of wires coming out of the chip could not exceed 40. So having 20 address pins to take the address (out of the die and the DIP) produced by the 8088 CPU could not be managed. Thus, the address lines and data lines had to share the same pins of the 8088 chip, by using them at different points of time during the memory access process (it is called a protocol in terminology of information exchange between two chips on a single board). This technique of sending two types of information over one bus is called multiplexing. With the advent of packaging technology, the pin-count has increased considerably. A new package is called Pin Grid Array (PGA) and can have up to 500 pins as of 1995. So multiplexing of address and data buses have been discontinued on the 386 and 486 and all other modern CPU chips. Now the challenge is to connect all these pins to other chips on the same printed circuit board (PCB) which serves as the motherboard without shorting them out. Thus SX motherboards remain easier to manufacture than DX motherboards albeit for a different reason.

part of the 'context' of a process, which must be saved when the process is interrupted, in order that the process can be resumed after a return from the interrupt. IP is the instruction pointer. It points to the instruction that is going to be fetched next at any point during the execution of a program. FLAGS register is the collection of the control and status flags, as shown in Figure 3. The blank bit-positions are for future designs of the same CPU dynasty.

In the next article, we will study the instruction set and assembly language programming of the base architecture.

Figure 3 Flags of the 8088

				OF	DF	IF	TF	SF	ZF		AF		PF		CF

Flags and their Role

Flags can be classified into 2 groups: control and status flags. The state of the control flags dictates how the CPU should execute instructions. There are 3 control flags, DF, IF and TF.

- Setting DF=1 makes string instructions automatically decrement SI and DI after every byte is moved. Resetting DF = 0 makes string operations auto-increment.
- Setting IF=1 lets the CPU acknowledge and service interrupts. Resetting IF=0 makes the CPU ignore them.
- Setting TF =1 puts the CPU into single-step mode. It stops after every instruction and allows the program to be examined closely.

Control flags can be set/reset by special instructions. For example, executing the instruction STI sets the interrupt flag IF = 1.

Status Flags of 8088

There are 6 status flags:

- AF is the auxiliary carry flag. It is set if there is a carry from the lower 4-bits into the higher 4-bits. It is used for decimal arithmetic.
- CF, the carry flag is set whenever there is carry from, or a borrow into the result after any arithmetic operation.
- OF, the overflow flag is set, if an arithmetic overflow occurs.
- SF, the sign flag is set whenever the result is negative, if interpreted in a 2's complement notation.
- PF, the parity flag is set whenever the result has an even number of bits set to 1.
- ZF is the zero flag. It is set to zero, whenever the result of an operation is 0.

The CPU sets or resets these bits after every result is produced. In addition, CF can be set/reset by executing special instructions. STC sets it to 1. CLC resets it to zero.

Learning Organic Chemistry Through Natural Products

4. Structure and Biological Functions

N R Krishnaswamy

Some interesting examples of the linkage between the structure and biological function of secondary metabolites in plants and animals are described.

The primary activities of a natural product chemist involve the isolation of a naturally occurring compound, determination of its structure and stereochemistry and finally its synthesis in the laboratory to confirm the structure. But this is not the end of the story. In a sense it is only the beginning since the *chemistry* of a natural product holds the key to answer the most important question: "Why do these compounds occur in nature?". It is logical to presume that a naturally occurring compound has some biological function to perform and there should be a connection between its chemistry and biological properties. Indeed, it was believed even at the very beginning of organic chemistry that certain classes of compounds of natural origin such as amino acids and proteins, lipids, carbohydrates and the nucleic acids - constitute the molecular basis of life. Their structures are tailor-made for their specific biological roles and no living

N R Krishnaswamy was initiated into the world of natural products by T R Seshadri at University of Delhi and has carried on the glorious tradition of his mentor. He has taught at Bangalore University, Calicut University and Sri Sathya Sai Institute of Higher Learning. Generations of students would vouch for the fact that he has the uncanny ability to present the chemistry of natural products logically and with feeling.

Biologists classify naturally occurring organic compounds into three types: (1) primary metabolites, (2) semantides and (3) secondary metabolites. The biological functions of the first two types are fairly well-known and they hold the key to fundamental biochemical reactions which control life processes. Secondary metabolites include the terpenoids, the alkaloids, the flavo-noids and related compounds which occur very widely in higher plants. According to Rembold (J Eder, H Rembold, *Naturwiss.*, 1992, *79*, 60) signal transmissions in nature through chemicals is only a part of the larger phenomenon of biosemiotics.

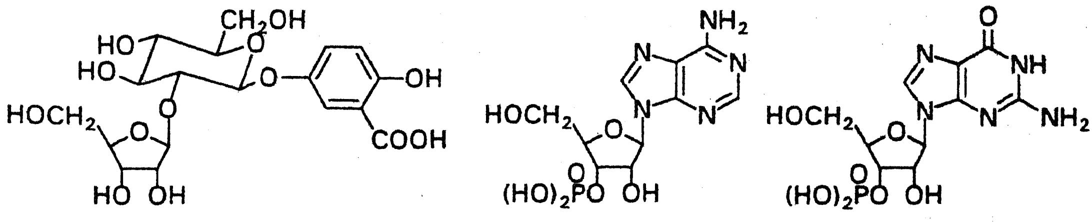
The plant *Mimosa asperta* has been mentioned in an ancient manuscript 'Plant Geography' written by Theophrastus during the reign of Alexander the Great. That the leaves of *Tamarindus indica* take nocturnal 'rest' was also known to the ancients. This observation was first recorded by Androsthenes in 325 BC. In 1729, the astronomer de Mairan observed that in *Mimosa pudica* the pinnules close and open at the usual time. The term 'Circadian Rhythm' to describe such phenomena was suggested by Hallberg.

The ogre Kumbhakarna of Ramayana fame was Ravana's younger brother. He was cursed by Brahma as a result of which he had to remain asleep for a long period at a time. He had to be woken up out of a deep slumber to fight against Rama and his army, and was killed by Rama on the battle field.

organism can exist without these compounds. However, for a long time the biological functions of some other classes of compounds such as alkaloids, terpenoids, polyphenolics were not clearly known and there was widespread belief that these compounds, classified as *secondary metabolites,* were waste products of metabolism! A lot of recent evidence shows that several of these secondary metabolites not only have important functions to perform but are also responsible for imparting unique and characteristic biological traits to the organisms in which they occur.

The Turgor Effect

Certain plants such as the 'Touch-me-not' (*Mimosa pudica)* the Tamarind *(Tamarindus indica), Acacia karroo* and *Mimosa asperata* are 'alert' and sensitive to external stimuli and subtle changes in incident light. They owe this capacity, termed the *Turgor effect,* to the presence of a few secondary metabolites classified as the turgorins. These compounds are presumably produced from readily available precursors *only* when the plant's external 'antennae' sense a possible danger or a change in daylight. The precursors themselves are ineffective in producing the turgor effect. After the lapse of a reasonable period of time the plant 'wakes up' after the turgorins are metabolised to inactive compounds. In this case one can see a phenomenon based on what one may call common sense! A specific compound with a particular biological effect is produced only when there is a need for it. If a turgorin had been present in the plant as a stable and permanent chemical constituent, the Touch-me-not plant would have become a botanical Kumbhakarna and a boon would have become a curse! The turgorins are phenolic and purine glycosides and the turgor effect is a direct consequence of their structures. Being glycosides they have a strong affinity for water. Their production or accumulation at a particular site, therefore, brings about the 'flow' of water and its structuring as in ice



Aryl - Glycoside *3′ - AMP* *3′ - GMP*

formation (a result of hydrogen bonding). The consequent change in water pressure produces an osmotic effect resulting, for example, in a shrinking of the pinnate leaf cells. The visible result is that the leaves close; they open up again when the turgorins are metabolised to inactive compounds. One of these leaf-movement factors isolated from *Mimosa pudica* has been characterised as the 5-riboglucoside of 2, 5-dihydroxy-benzoic acid. In this plant, leaf movement is also brought about by two nucleotides which have been identified as adenosine 3′-monophosphate (3′-AMP) and guanosine 3′-monophosphate (3′-GMP). Monoglucosides of gallic acid with one or two sulfate groups on the sugar ring have been recognised as the major leaf-movement factors of *Acacia karoo.*

Semiochemicals

It is now becoming increasingly clear that secondary metabolites are partly responsible for some of the species-specific characteristics of plants and insects. For instance, the ability of a species to interact in a specific manner with other forms of life in any given environment can often be traced to a specific secondary metabolite that is characteristic of the species. Thus, these compounds regulate plant-plant, plant-insect, plant-vertebrate, insect-insect interactions, etc., in an eco-system. Collectively, such

The ability of a species to interact in a specific manner with other forms of life in any given environment can often be traced to a specific secondary metabolite that is characteristic of the species.

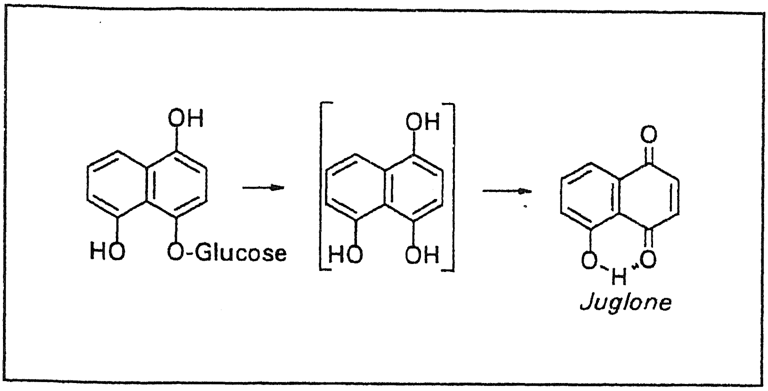
Parthenium hysteroporus, more commonly known as Congress grass (because of its white coloured heads) is believed to have been brought to India along with a consign- ment of wheat under the PL-480 scheme. Since then it has spread to almost all parts of the country and has become a plant menace. Another 'colonizer' but less aggressive is *Eupatorium odoratus* which is mostly confined to the state of Kerala where it is popularly known as Communist green! This plant also belongs to the family of Asteraceae.

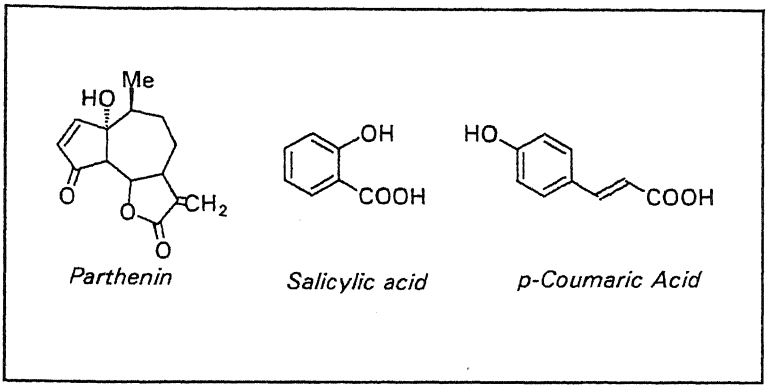
Parthenium hysteroporus owes its aggressiveness mainly to the presence of sesquiterpene lactones such as parthenin and certain cinnamic acid derivatives which are plant-growth inhibitors.

compounds are known as *semiochemicals* as they are the chemical mediators in a complex network of signal-communication in any eco-system. These include different types of insect pheromones and allelochemicals. A few interesting examples are described in the following paragraphs.

Allelochemicals

The system of communication network through chemicals between members of a plant community is known as *allelopathy*. It is a common observation that most plants within a heterogeneous commune individually maintain healthy growth. However, there are certain plants which effectively inhibit the growth of *other* species in their neighbourhood. One such notorious colonizer is *Parthenium hysteroporus* which belongs to the family Asteraceae (Compositae). The plant owes its aggressiveness mainly to the presence of sesquiterpene lactones such as parthenin and certain cinnamic acid derivatives which are plant-growth inhibitors. Another plant which is capable of protecting its territorial rights is the Walnut tree, botanically known as *Juglans nigra* . The leaf canopy of this tree provides a cover under which most other plants do not grow. But this plant is not as aggressive as Parthenium and is eco-friendly to certain plants such as the Kentucky blue-grass (*Poa pratensis*), which normally grow under a Walnut tree. The allelopathic effect of the Walnut is due to the presence of the 4-*O*-glucoside of 1, 4, 5-trihydroxynaphthalene in the leaves. Being a water-soluble compound, it gets washed off the foliage by rain water and dew drops. When it comes into contact with the microorganisms in the soil under the tree, it undergoes cleavage and oxidation to yield 5-hydroxynaphthoquinone, known as *Juglone*, which is a specific phytotoxin. In this example one can see the 'intelligent' use of simple chemical principles in the production of a toxic compound by a plant





outside its own 'body'. The precursor of the toxin has a sugar 'cap' which can be easily removed and a 1, 4-dihydroxy benzene moiety which has a low oxidation potential. The precursor itself is non-toxic and does not interfere with the normal growth of the tree.

The Oak tree, *Quercus falcata* also produces a simple water soluble allelopathic agent, salicylic acid. Other phenolic acids, such as *p*-hydroxycinnamic acid, also possess plant-growth inhibitory activity and are secreted along with some quinones by plants such as *Adenostema fasciculatum* and *Arctostaphylos glandulosa.* These two plant species are shrubs which are natives of the California chapparal where they inhibit the growth of other herbaceous plants. However, once in about twenty years the aerial parts of these shrubs get burnt in the California fire cycle, enabling the dormant seeds of other

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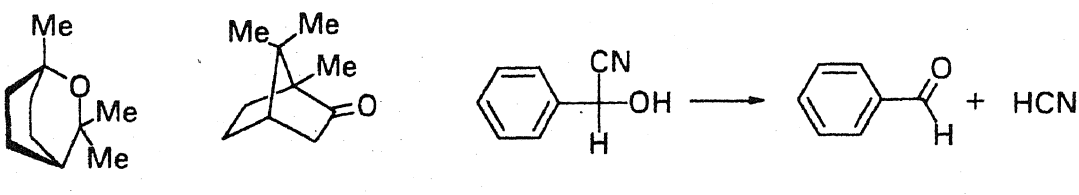


1,8-Cineole Camphor Mandelonitrile Benzaldehyde

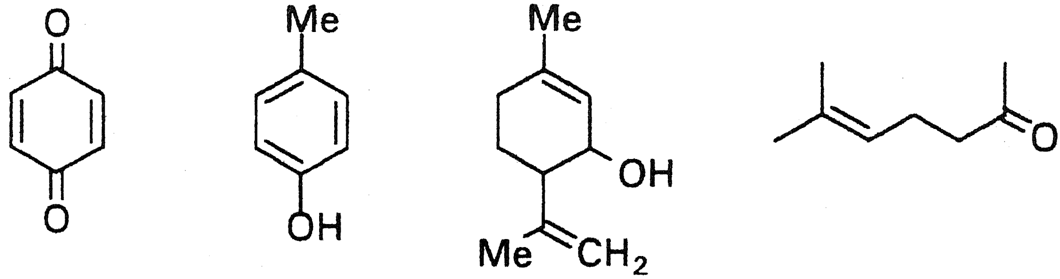
herbaceous species to germinate. Thus, soon after the break-out of the fire, these herbs flourish, grow to maturity and shed seeds which get embedded in the soil. By this time, the aggressive *Adenostema* and *Arctostaphylos* shrubs would have regained their territories and their autocratic rule, supported by *p*-coumaric acid and the quinones, would continue for another twenty years!

In contrast to the Walnut and Oak trees, the leaves of *Salvia leucophylla* produce a volatile oil comprising of cineole, camphor and related compounds. The oil which forms an azeotrope[1] with water gets volatilised, like the oil of *Eucalyptus*, into the atmosphere and then gets absorbed by the dry soil. The low concentrations of these compounds in the soil are enough to inhibit the germination and growth of grass and herbs which would have otherwise formed a thick undergrowth soon after the onset of the winter rains.

[1]Azeotrope is a mixture of liquids in which the boiling point remains constant during distillation, at a given pressure, without change in composition.

Defensive Secretions of Insects

There are several ways in which insects protect themselves against possible predators and adverse climatic conditions in their natural habitats. One mode of defence is to project a 'scary' physical appearance, such as donning a red coat which serves as a warning signal to predators because of the association of the colour with proven vicious anthropods such as the centipede. For example, the slow moving, quite harmless millipedes sport this colour so as to confuse a

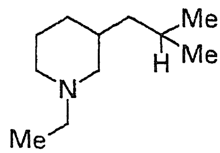


p-Benzoquinone p-Cresol Isopipertinol 6-Methyl-5-hepten-2-one

predator which could mistake the millipede for a centipede at first glance. But this deception may not always work and the millipede does need a second line of defence. And what can be more lethal than a chemical in a warfare! Millipedes are found in large numbers in moist situations, particularly in the sub-soil under deciduous trees. They are larger than the centipedes and much more sluggish in their movement and hence more susceptible to attack by insectivores. There are different orders, genera and species among the millipedes and the chemicals used by them for defence are equally varied. Millipedes of the order *Polydesmus,* when attacked by a predator or otherwise disturbed, secrete mandelonitrile which breaks up into benzaldehyde and hydrogen cyanide. Millipedes of the order *Julia* use *p*-benzoquinone for their defence against predators. This lachrymatory compound also possesses anti-microbial activity. Another millipede produces *p*-cresol for its defense.

Insects require chemicals not only for defending themselves against predators but also to protect themselves from possible 'accidents' such as from drowning. An illustrative example is the innovative use of a surface-active chemical by the water-beetle, *Stenus coma*. This tiny blue-green insect which is only 5 mm long and weighing a grand 2.5 mg is capable of swimming on water at the incredible speed of 50 to 75 cm per

Insects require chemicals not only for defending themselves against predators but also to protect themselves from possible 'accidents' such as from drowning



Stenusin

In addition to the compounds mentioned in the text, certain types of millipedes use more complex compounds such as dialkyl quinazolinones and nitro pyrrolizidine for their defence. These compounds resemble some alkaloids of plant origin.

second! It needs protection during its search for food along river banks since it may otherwise fall into the flowing water. What enables this tiny creature to perform such an amazing feat is its abdominal secretion which resembles, in smell, the oil of Eucalyptus. This oil obtained from 1000 beetles has been found to contain 0.8 mg of a mixture of 1, 8-cineole, isopipertinol, 6-methyl-5-heptenone and a tertiary amine, stenusin. Stenusin is only sparingly soluble in water but has a high spreading pressure because of its high surface activity. It gives the beetle the protection it needs when its underparts are exposed to the microflora in the water. The oil spreads on water and enables the beetle to glide on its surface. Thus, this little beetle knows enough chemistry to keep it floating and protect itself from water borne microorganisms!

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Knots

How To Distinguish Two Knots If You Must

V S Sunder

In this article[1] the reader is introduced to some basic notions of *knot theory*, including the use of the 'skein relations' in computing the celebrated (one-variable) polynomial invariant of knots (and more generally, of links or 'multi-component knots') which was discovered by Vaughan Jones more than a dozen years ago.

After spending over a decade at Indian Statistical Institute (Delhi and Bangalore), V S Sunder is currently at Institute of Mathematical Sciences, Madras.

Knots considered by mathematicians do not have loose ends.

Definition 1. A *knot* is the image of the unit circle

$$S^1=\{z \in \mathrm{C} : |z|=1\}$$

under a continuous injective[2] map into $\mathbf{R}^3$.

[2] A map f from a set S into a set T is called *injective* if distinct elements in S get mapped to distinct elements in T; i.e., $x \neq y$ implies $f(x) \neq f(y)$ (equivalently, $f(x) = f(y)$ implies $x = y$). For instance the maps from $\mathbf{R}$ to $\mathbf{R}$ given by $x \to x^3$ and $x \to e^x$ are injective, but not $x \to x^2$ or $x \to \sin x$.

Given two tangled heaps of string, each knotted in some complicated manner, how does one go about recognizing or checking whether they are essentially the same? Can one heap be transformed (without the use of scissors!) into the other? This is the central problem of knot theory.

Example 1. (refer Figure 1).

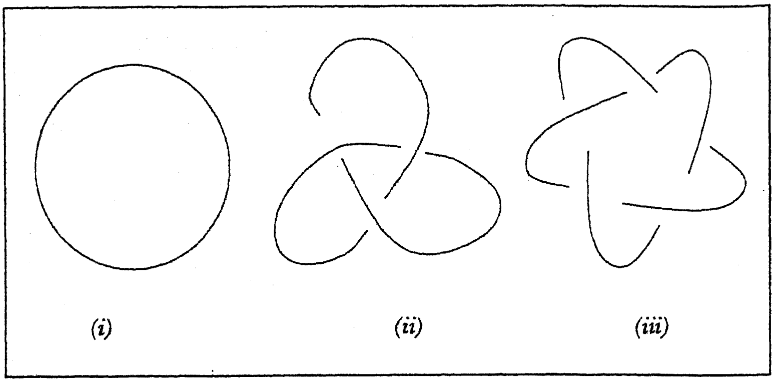
(i) The so-called *unknot* is the simplest example; it is the image of S^1 under the natural embedding into $\mathbf{R}^3$. (It is, however, not a very interesting knot.)

(ii) This is called the *right-handed trefoil* to distinguish it from its 'left-handed' counterpart. (The left-handed trefoil is denoted by $T\_$ and is illustrated in *Figure 3.*)

(iii) This knot might be called the *right-handed pentafoil* in analogy with the last example.

[1] The contents of this article were the basis of a lecture given by the author at the Mathematics Training and Talent Search Programme at IIT, Bombay in June, 1994; these notes were (modulo some editorial rights exercised by the author) compiled by Varsha Dani and Amritanshu Prasad, who were both undergraduate students at that time. Most of the material in the various 'boxes' were provided by Shailesh Shirali.

Figure 1 (i) U_1 (ii) T_+ (iii) P_+



Equivalence of Knots

Two knots will be thought of as being the same if it is possible to continuously deform one into the other. More precisely, we have the following definition.

Two knots will be thought of as being the same if it is possible to continuously deform one into the other.

Definition 2. Two knots K and K' are said to be equivalent if there exists a continuous map $F: [0,1] \times \mathbf{R}^3 \rightarrow \mathbf{R}^3$ such that, if we write $f_t(x) = F(t,x)$, then we have:

(a) f_t is a homeomorphism of $\mathbf{R}^3$ onto itself;
(b) f_0 is the identity map of $\mathbf{R}^3$; and
(c) $f_1(K) = K'$.

It is a fact that two knots are equivalent if and only if it is possible to find an *orientation-preserving* homeomorphism of $\mathbf{R}^3$ onto itself which maps one knot onto the other.

A map between two spaces is a *homeomorphism* if it is continuous and has a continuous inverse; in this case the two spaces are *homeomorphic* to one another. Visually one can think of a homeomorphism as a continuous deformation of one object to another. For instance one can continuously deform a cube into a sphere and a teacup with a handle into a ring or closed tube. (Refer V Pati's article in ***Resonance***, Vol 1, No.4, 1996). However one cannot continuously deform the teacup into a sphere. (Why?)

In a sense, the central problem of knot theory is that of determining whether or not two given knots are equivalent, and of finding 'efficient methods' of distinguishing between two knots which are really inequivalent.

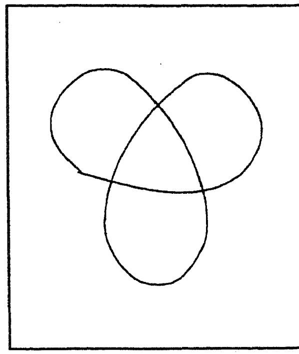


Figure 2 A knot projection

Knot-projections and Knot-diagrams

As in *Figure 1*, we shall often find it convenient to think of a knot by using plane diagrams. If we simply project a knot onto a plane, we will lose some information about the knot if there are 'crossings' or intersections in the projected figure. This is overcome, as we did in *Figure 1*, by indicating the lower strand at a crossing by a broken line.

Figure 2 is the projection of each of the knots shown in *Figure 3*. (It is a fact that those three knots are piecewise inequivalent, as will be shown by our subsequent computation of the so-called *Jones polynomial* of these knots.)

Notice that we can appeal to the above trick of distinguishing between 'over-crossings' and 'under-crossings' only if there are at most two strands at a crossing. Fortunately for us, it turns out that this is sufficient, if we restrict ourselves to the so-called *tame* knots. (A knot is said to be tame if it is equivalent to one which is given by a 'smooth' – or, equivalently, a piecewise-linear – embedding of the unit circle.) It is a fact that, given a tame knot, it is always possible

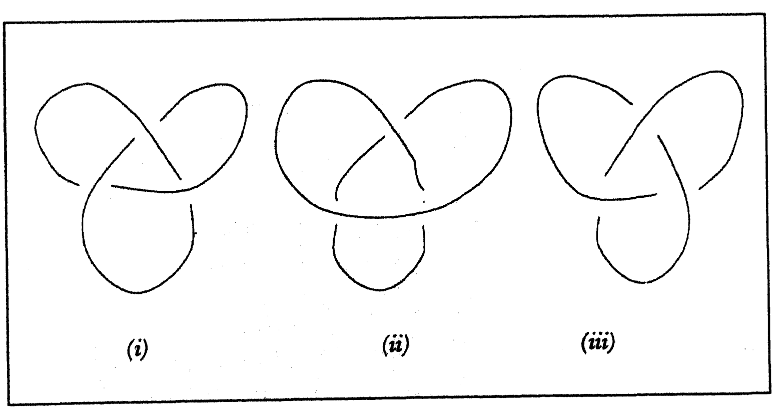
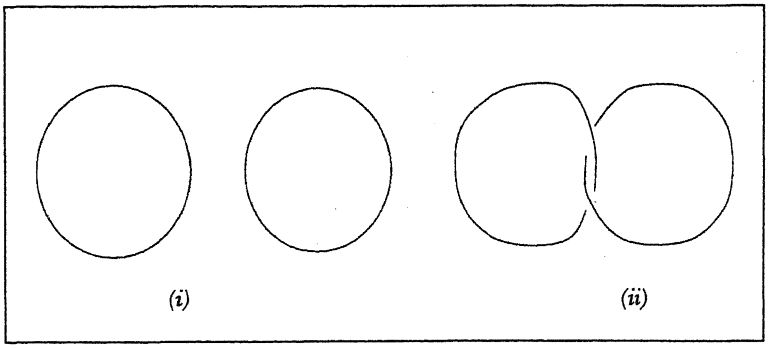


Figure 3 (i) T_+ (ii) U_1 (iii) T_-

Figure 4 (i) U_2 (ii) H



to choose a plane such that the projection of the knot onto the plane will have the following two pleasant features: (a) exactly two strands cross at any intersection and (b) every intersection is 'transverse' – meaning that the strands are not 'mutually tangential' at the point of crossing.

We shall find it convenient to also consider *links* or 'multi-component knots'. (More precisely, a link is the image in $\mathbf{R}^3$, under a continuous injective map, of a disjoint union of finitely many copies of the unit circle.) Two simple examples of 'two-component' links are given below:

- The first example is called the *unlink on two components*, because it consists of two unknots which are not 'linked together' at all. In an entirely similar manner, we can (and will) talk of an unlink on n components, and denote it by U_n, with the obvious understanding that U_1 denotes the unknot.
- The second example is sometimes referred to as the *Hopf link;* at least intuitively, the reader should be convinced that this link is not equivalent to U_2. (Exactly as for knots, we say that two links K and K' are equivalent if they are related by a function F as in *Definition 2*.)

More generally, we shall consider *oriented links*, where an 'orientation' on a link is specification of a preferred direction – clockwise or anti-clockwise, in the case of the unknot – in each component of the link. Thus there are four possible ways of orienting the Hopf link, of which we list two in *Figure 5*.

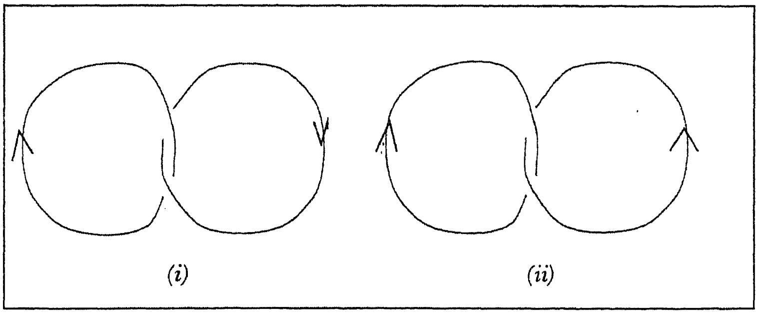


Figure 5 (i) H_1 (ii) H_2

We shall say that two oriented links are equivalent if there exists a map F which, in addition to having the properties demanded of it in *Definition 2*, also 'preserves the orientations' in each component. (It is a fact - whose truth is verified by our subsequent computations with the Jones polynomial - that the two oriented links, presented above, are inequivalent.)

The means by which we will be able to distinguish between some pairs of inequivalent (oriented) links involves the important notion of a *knot-invariant* or a *link-invariant*.

Link Invariants

Let $\mathcal{L}$ denote the collection of all (oriented) links. A function

$$\mathcal{L} \xrightarrow{P} S$$

where S is a set, is said to be a link invariant if $P_{L_1} = P_{L_2}$ whenever L_1 and L_2 are equivalent links. Here, the notation P_L indicates the image of L under P. (In an exactly similar

An *invariant* is an extremely important and useful entity, as it captures a property of the system or object at hand which does not change when the object is subjected to some given group of transformations. For instance, with reference to the group of rigid movements in 3-space, relations such as perpendicularity remain unchanged; distances do not change, nor do angles. If we widen the group of transformations to include all invertible linear transformations, then distances and angles are not invariant, nor are relations such as perpendicularity, but properties such as collinearity of a set of points or concurrence of a set of lines stay unaffected. The degree of a curve is another invariant in this case. Many such examples can be listed.

A *Laurent polynomial*, unlike the polynomials one normally encounters, can have terms with negative degree; for instance $f(t) = t^{-1} + t$.

manner, we can talk of invariants of oriented links.) Hence, by definition, if a link invariant assigns different values to two links, the links are necessarily inequivalent.

We begin by looking at a few simple examples of link invariants.

- The number $c(L)$ of connected components of a link is clearly an invariant of links (and hence of oriented links).
- If L is any link and if we are permitted to cut a link, then deform it, and then re-stick the two loose ends together, and if we are permitted to perform this operation as many times as we wish, it must be clear that we can start with any link and eventually arrive at an unlink (with necessarily the same number of components as the link we started with). A further moment's thought shows that the smallest number $k(L)$ of such 'splices' that are necessary to transform the link L into an unlink, is an invariant of the link L.
- Notice that if two links L and L' are equivalent, then their complements $\mathbf{R}^3 - L$ and $\mathbf{R}^3 - L'$ *are homeomorphic*[3] as topological spaces; consequently, any 'invariant' of the topological space $\mathbf{R}^3 - L$, which we shall henceforth refer to as the link-complement will also be an invariant of the link L. For the reader who knows what this means, one example of such an invariant of a link L is the isomorphism class of the fundamental group $\pi_1(\mathbf{R}^3 - L)$; this invariant is often referred to as the *link-group* of L.

The Alexander Polynomial

One invariant of an oriented link, that was obtained as an invariant of the link-complement in the manner described above, is the Alexander polynomial of the link, named after the topologist who discovered this invariant. For each oriented link L, the associated Alexander polynomial $\Delta_L(t)$ is a Laurent polynomial in a variable which we call $\sqrt{t}$ in keeping with established convention; to be explicit, $\Delta_L(t)$ is an expression

[3] As indicated earlier, spaces X and Y are homeomorphic if there exists a continuous mapping $f : x \to Y$ which is invertible and has a continuous inverse $g : Y \to X$; i.e., there exist continouous maps f, g as above so that $f(g(y)) = y$ for all y in Y and $g(f(x)) = x$ for all x in X.

of the form $\sum_{n=-N}^{N} a_n (\sqrt{t})^n$, where the a_n' s are integers.

In attempting to obtain an algorithm to compute the Alexander polynomial of a link, the British mathematician J H Conway arrived at a remarkable property of this polynomial invariant, which led easily to the desired 'inductive formula' for computing the Alexander polynomial. In order to describe this formula, we need to set up some notations and conventions.

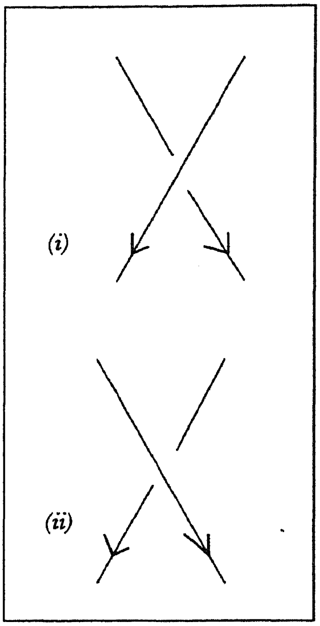
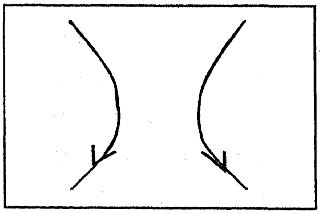


Figure 6 (i) Positive (ii) Negative

To start with, we only work with oriented link-diagrams. (Secure in the knowledge that the Alexander polynomial is actually a link invariant, we need not be worried by the possibility that very different looking link-diagrams might yield equivalent links. Further, we will only work with tame knots, and will hence need to work only with link-diagrams with at most double-crossings which are transverse.) Given a crossing in a link-diagram, we can (rotate it, if necessary, and) assume that the crossing has one of the two forms shown in *Figure 6*. We adopt the convention of referring to the first as a positive and the second as a negative configuration. Finally we shall refer to the 'configuration' shown in *Figure 7* as a *zero* configuration.

We will say that three oriented link-diagrams are *skein-related* if they are identical except at one crossing, where they have the positive, negative and zero configurations respectively. In such a case, we shall label them simply as L_+, L_- and L_0 respectively. One example of such a skein-related triple of oriented link-diagrams is given in *Figure 8*.

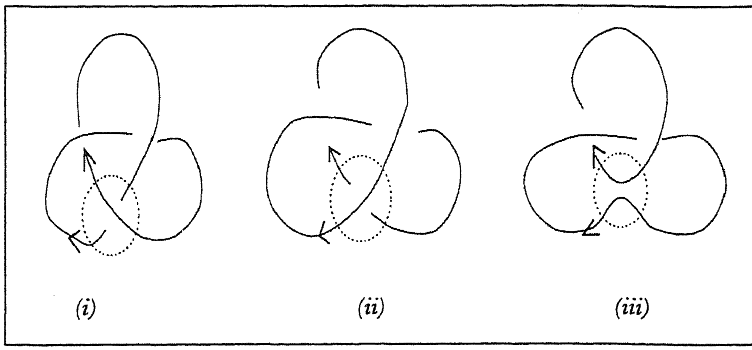
Figure 7 Zero configuration



Conway found that if L_+, L_- and L_0 are arbitrary oriented link-diagrams which are skein-related, then their Alexander polynomials satisfy the linear relation

$$\Delta_{L_+}(t) - \Delta_{L_-}(1) = \left(\frac{1}{\sqrt{t}} - \sqrt{t}\right) \Delta_{L_0}(t) \qquad (1)$$

Figure 8 *(i)* $T_+ = L_+$ *(ii)* $U_1 = L_-$ *(iii)* $H_1 = L_0$



The above relation, together with the fact that $\Delta_{U_1}(t) = 1$, completely determines the Alexander polynomial of all oriented tame links. Rather than study the details of why this is true we will discuss the *Jones polynomial* invariant of links, and show how to compute it using a skein related inductive procedure. (That computation should tell the reader why the uniqueness assertion made earlier is valid.)

The Jones Polynomial

Unlike the Alexander polynomial, the next link invariant that we will discuss is *not* an invariant of the link-complement. This invariant - the Jones (one-variable) polynomial invariant of an oriented link - is named after the operator algebraist who discovered it. Just like the Alexander polynomial, the Jones polynomial $V_L(t)$ of an oriented link is a Laurent polynomial in a variable $\sqrt{t}$, with integer coefficients; this invariant is also 'normalised' so that its value at the unknot is the constant polynomial 1; and the Jones polynomial also satisfies a skein relation analogous to equation (1). Specifically, we have:

The Jones polynomial $V_L(t)$ of an oriented link is a Laurent polynomial in a variable $\sqrt{t}$, with integer coefficients

$$t V_{L_+}(t) - \frac{1}{t} V_{L_-}(t) = \left(\frac{1}{\sqrt{t}} - \sqrt{t}\right) V_{L_0}(t) \qquad (2)$$

for any skein-related triple L_+, L_-, L_0 of oriented link-diagrams; and also

$$V_{U_1}(t) = 1 \qquad (3)$$

:ight be worth emphasising here, that the difficult part of entire game is ensuring that one has an invariant of links. ıt makes this part of the analysis acceptable, in the case of Alexander and Jones polynomials, is some serious work in *braic topology* and *operator algebras* respectively; these hematical inputs are beyond the scope of this article. The tion we adopt here is that some benevolent providence supplied us with the information that there does exist a -invariant which satisfies the displayed skein-relation, we will see what mileage can be gained from this stroke of d fortune.

: Inductive Method of Computation Using the in Relations

will now indicate how the skein relation (2) can be used, rinciple, to compute the Jones polynomial of any oriented e link, and then illustrate the discussion by computing the ıriant for the trefoil knots. Given any oriented (tame) -diagram, we will 'measure its complexity' by an ordered (n,k) of integers, where n denotes the number of crossings :he diagram, and k denotes any integer such that, by :ing k judicious 'sign-changes' in the diagram - i.e., nging some l under-crossings to over-crossings and some) over-crossings to under-crossings - it is possible to obtain ık-diagram which represents an unlink (with necessarily same number of components as in the initial diagram).

;et a better feeling for the number k, look at the manner in ch the invariant $k(L)$ was defined earlier. We deliberately se this k, rather than $k(L)$, since it will usually not be clear, egin with, as to just what $k(L)$ would be; this is because if do not already know that the trefoil is not equivalent to unknot, then we cannot say whether $k(T_+)$ is zero or not.

adopt the following 'inductive procedure'. We order the ered pairs (n, k) according to the lexicographic or

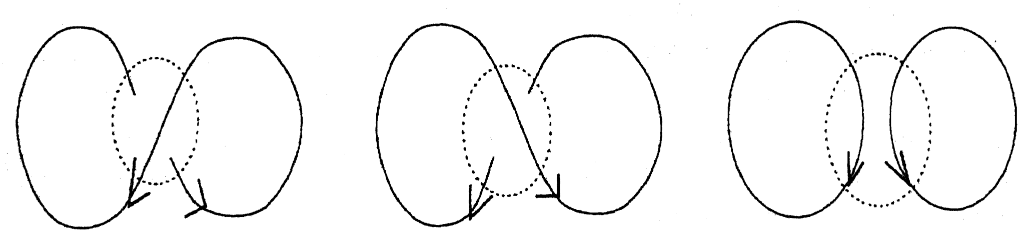
dictionary order; thus we shall say that $(n, k) \leq (m, j)$ if either $n<m$ or $n = m$ and $k \leq j$. Thus, the 'simplest' link-diagrams correspond to $n = 0$, these representing unlinks. Next if a given link-diagram corresponds to a pair (n, k), there are two possibilities: (i) either $k = 0$, in which case the diagram represents an unlink; or (ii) $k > 0$, in which case, by considering a suitable crossing in that diagram (which is among one set of k crossings which can be changed to convert the given diagram to one which represents an unlink), we are led to a skein-related triple L_+, L_-, L_0 of oriented link diagrams such that the diagram we started with is either L_+ or L_-, and such that L_0 has only $(n - 1)$ crossings. Thus, any link-diagram either represents an unlink, or there exists a skein-related triple of diagrams in which two of the diagrams represent 'simpler' link-diagrams than the third (which is the given) link diagram.

In order to adopt this procedure effectively, we must compute the Jones polynomial of the unlinks; this is done by considering the following skein-related triple of link-diagrams shown in *Figure 9.*

The skein-relation (2) implies that

$$\left(t - \frac{1}{t}\right) V_{U_1}(t) = \left(\frac{1}{\sqrt{t}} - \sqrt{t}\right) V_{U_2}(t)$$

***Figure 9** (i) $L_+ = U_1$ (ii) $L_- = U_1$ (iii) $L_0 = U_2$*



(i) (ii) (iii)

In view of equation (3) and the fact that the 'cancellation law' is valid in the collection of Laurent polynomials (which is an integral domain in the language of 'ring theory'), we deduce that

$$V_{U_2}(t) = -\left(\frac{1}{\sqrt{t}} + \sqrt{t}\right). \tag{4}$$

The reader should note that an identical argument – with the pair (U_1, U_2) replaced by (U_n, U_{n+1}) – shows that

$$\begin{aligned} V_{U_{n+1}}(t) &= -(\sqrt{t} + \frac{1}{\sqrt{t}})\ V_{U_n}(t) \\ &= \ \ldots \\ &= \left\{-(\sqrt{t} + \frac{1}{\sqrt{t}})\right\}^n \end{aligned} \tag{5}$$

Computation of the Jones Polynomial of Some Links

We will now apply the procedure outlined above to compute the Jones polynomial of the right-handed trefoil, which we assume has been oriented as in *Figure 8*. That figure, together with the relation (2), shows that

$$tV_{T_+}(t) - \frac{1}{t} = \left(\frac{1}{\sqrt{t}} - \sqrt{t}\ \right)\ V_{H_1}(t) \tag{6}$$

where H_1 is the Hopf link with the orientation as shown in *Figure 8*.

So we need to compute $V_{H_1}(t)$; for this, consider the skein-related triple of oriented link-diagrams given in *Figure 10*.

Deduce from the skein relation (2) and equation (4) – after some minor manipulations – that

$$V_{H_1}(t) = -\sqrt{t}\,(t^{-1} + t^{-3}) \tag{7}$$

Substitute this into equation (6) and find – after some more minor manipulations – that

$$V_{T_+}(t) = t^{-1} + t^{-3} - t^{-4} \tag{8}$$

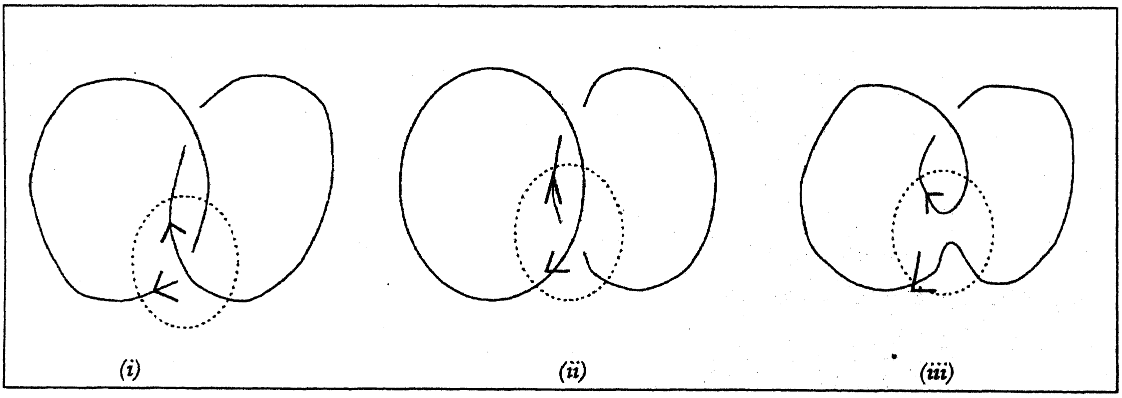
The reader should have little difficulty in starting with the left-handed trefoil T_-, obtaining a skein-related triple where L_+ is equivalent to U_1, L_- is the link-diagram of T_- occurring in *Figure 3*, and L_0 is the link-diagram denoted by H_2 in *Figure 5*, and proceeding exactly as we did above to establish the following facts:

$$V_{H_2}(t) = -\sqrt{t}\,(t^2 + 1)$$
$$V_{T_-}(t) = t + t^3 - t^4 .$$

It follows, in particular, that the oriented links T_+ , T_- , H_1 and H_2 are pairwise inequivalent.

Thus the Jones polynomial does indeed distinguish between the right-handed trefoil and the unknot. There is still no example of a knot K which is not equivalent to the unknot but such that $V_K(t) = 1$. We list below some properties of the Jones polynomial, which can be proved using the same inductive procedure that we outlined earlier. These facts are illustrated by the four links mentioned in the preceding paragraph.

***Figure 10** (i) $L_+ = H_1$ (ii) $L_- = U_2$ (iii) $L_0 = U_1$*



Proposition : Let L denote an oriented tame link. Then the following statements hold:

(a) If $c(L)$ is odd (for instance if L is a knot) then $V_L(t)$ is a Laurent polynomial in t with integer coefficients; and if $c(L)$ is even, then $V_L(t)$ is $\sqrt{t}$ times a Laurent polynomial in t with integer coefficients.

(b) If $\widetilde{L}$ denotes the oriented link obtained by reflecting the link in a plane, then,

$$V_{\widetilde{L}}(t) = V_L(t^{-1}) .$$

(c) Let K be a connected component of L, and let L' be the oriented link obtained by reversing the orientation in K and preserving the orientation in the other components of L; then,

$$V_{L'}(t) = t^{3\lambda} V_L(t) \quad ,$$

where λ denotes the 'linking number' of K and $L - K$ (which is defined to be zero if $K = L$).

We wish to point out two consequences of the above proposition:

- Firstly, it may be deduced easily from (c) that the two oriented knots obtained from an unoriented knot have the same Jones polynomial; thus, the Jones polynomial yields an invariant of unoriented knots, and in particular, the left and right-handed trefoils are inequivalent as (unoriented) knots.
- Secondly, a link L and its mirror-image $\widetilde{L}$ have homeomorphic link-complements, and consequently no invariant which 'factors' through the link-complement – such as the Alexander polynomial – can distinguish between a link and its mirror-image. Thus, the Jones polynomial is quite a different kind of invariant from the others discussed here.

Is there a knot K, not equivalent to the unknot, for which $V_K(t) = 1$? The answer to this question is not known. (If the answer is "NO" then the Jones polynomial would provide a definitive way of verifying that a knot is indeed knotted. Curiously, this is not true of the Alexander polynomial; there do exist examples of knots, not equivalent to the unknot, for which Δ t = 1.)

Suggested Reading

The interested reader might want to take a look at the following survey article on the Jones polynomial, which makes good reading and also contains a list of references which the reader may use as a starting point on the trail of the literature on knots:

The Jones polynomial, by Pierre de la Harpe, Michael Kervaire and Claude Weber, l'Enseignement Mathematique, 32, pp 271-335. 1986.

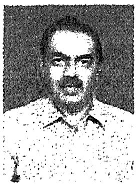
The reader can also look at

The theory of Knots, by L Neuwirth, *Scientific American*, pp 84-96. Jan 1979.

A Crab in the Lab that Identified High and Low Tides in the Sea Two Miles Away

The Rediscovery of Tidal Rhythms in India

M K Chandrashekaran

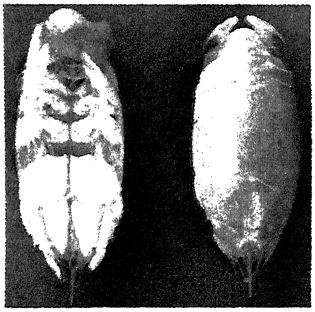


M K Chandrashekaran has studied biological rhythms in plants, fruitflies, crabs, mice, bats, squirrels and humans. Having established an active school of research in chronobiology at the Madurai Kamaraj University, he has just moved to the Jawaharlal Nehru Centre for Advanced Scientific Research at Bangalore and plans to focus his attention on rhythms in social insects.

The author describes his 'choice' of a Ph.D. dissertation topic in the sixties, the interactions with his advisor, the rhythms of the mole crab and the serendipity of success in research, in a candid and humorous fashion.

I became a chronobiologist by the fortuitous re-discovery of tidal rhythms in the swimming activity and oxygen consumption of the mole crab, *Emerita asiatica* at Madras (*Figure 1*). Books stated that this crab lived in the intertidal region of the sea always under a few centimetres of water. This would hardly be logically possible for the sea rises by about 1.5 to 2m every 12.4 hours causing high tides. Similarly, the sea ebbs once every 12.4 hours causing low tides. Thus identical tides occur roughly 12 hours apart. It therefore follows that the crab must migrate up and down the beach in order to be able to live constantly under a few cm of sea water. It strains off tiny copepods and protozoans with its feather like antennae especially from the seaward washes of waves. Another prominent tidal migrant is a mussel called *Donax cuneatus* in the Madras coast.

Figure 1 Photograph showing ventral (left) and dorsal (right) view of an adult female Emerita asiatica.



The Setting

In the early sixties the Zoological Research Laboratory of the University of Madras was still housed in a lovely building (now flanking the southern side of the Centenary building) with facilities for running sea water. There was a separate aquarium building with capacious water tanks with heavy glass face containing sea water. Professor C P Gnanamuthu,

M.A., D.Sc., F.Z.S. was the Director and ran the laboratory rather sternly. The faculty members and research scholars were much in awe of him. Dr. Gnanamuthu seemed to secretly like young people but appeared too shy to give expression to this sentiment. I can vouch for the fact that he enjoyed teaching M.Sc. classes and put a great deal of effort into his lectures. He spoke and wrote chaste English and had a good sense of humour.

"It is not for nothing that the scholar invented the Ph.D. thesis as his principal contribution to literary form. The Ph.D. thesis is the perfect image of his world. It is work done for the sake of doing work - perfectly conscientious, perfectly laborious, perfectly irresponsible"

Archibald Macleish

It was very difficult in those days to become a research scholar and register for the Ph.D. degree. Only B.Sc. (Hons) and M.A. candidates with a first class made it. There was just *one* U.G.C. scholarship in a year and the students were drawn mostly from the Southern states. It was never clear to any of us what awaited us after the Ph.D. degree was awarded. The whole undertaking was one big gamble. Three copies of the Ph.D. thesis were sent to three foreign (generally English) examiners many of whom were Fellows of the Royal Society. The examiners generally, having little idea of the hardships under which the research was carried out, were invariably harsh with criticisms, particularly in matters of methodology. Roughly 50 percent of the theses were turned down of which some were recommended for resubmission after suitable modifications. Since the process often took close to a year the candidates would have left and the thesis just remained in the laboratory.

It was my Ph.D. research mandate to study the 'basal' metabolism of tropical poikilotherms. It was fairly obvious by the time I began my research in 1960 that there was no basal metabolism in poikilotherms.

Research Leading to Ph.D.

To return to the beginning. In zoology during the tenure of Prof. Gnanamuthu as the Director of the Zoological Research Laboratory, which lasted from 1946 to 1963, the research scholars did not choose the topic of their own Ph.D. research but were given topics. The M.Sc. 'by examination' candidates were especially unsuited even to suggest a topic for themselves. Similarly, it was a matter of sheer chance as to

M J Wells visited us from U.K. sometime in 1962-63 and after discussing my research plans with me, told me that he was sorry for my plight.

which faculty member one ended up with for research. It was my lot to work with Prof. Gnanamuthu who, on several counts, deserved to be better known and appreciated as a scientist.

It was my Ph.D. research mandate to study the 'basal' metabolism of tropical poikilotherms. The latter ponderous word refers to all animals save birds and mammals. It was fairly obvious by the time I began my research in 1960 that there was *no* basal metabolism in poikilotherms. Ever since the monograph on respiration by the great August Krogh, published in 1919, students of physiology knew that the basal metabolism of poikilotherms was called 'standard metabolism'. The stipulated conditions for measurement of the 'basal metabolic rate' (BMR) in humans were a light breakfast 8 hours prior to measurements of oxygen consumption of subject, a relaxed (reclining) posture and listening to light music. These were hardly conditions I could have imposed on my crabs. Prof. Gnanamuthu strongly felt (as he did on most other matters) that the extreme variabilities characterising O_2 consumption values of invertebrates and lower vertebrates were 'part and parcel' of the business of life and therefore 'the minimum energy compatible with the maintenance of life' and therefore 'basal'. I was a helpless pawn in this ideological warfare between my research supervisor and the school of the Canadian fish physiologist F E J Fry and his students, prominent among them S V Job, then reader in the laboratory and sitting just four rooms away from the Director's office. M J Wells visited us from U.K. sometime in 1962-63 and after discussing my research plans with me, told me that he was sorry for my plight.

Photograph of Dr. C P Gnanamuthu with the author made in early 1964

A Mad Crab

Among the several animals I examined (an estuarine anemone, an estuarine annelid, an intertidal bivalve, a fiddler crab, a land crab and an anomuran crab) was a mole crab *Emerita asiatica*, which was totally aquatic. I came every day

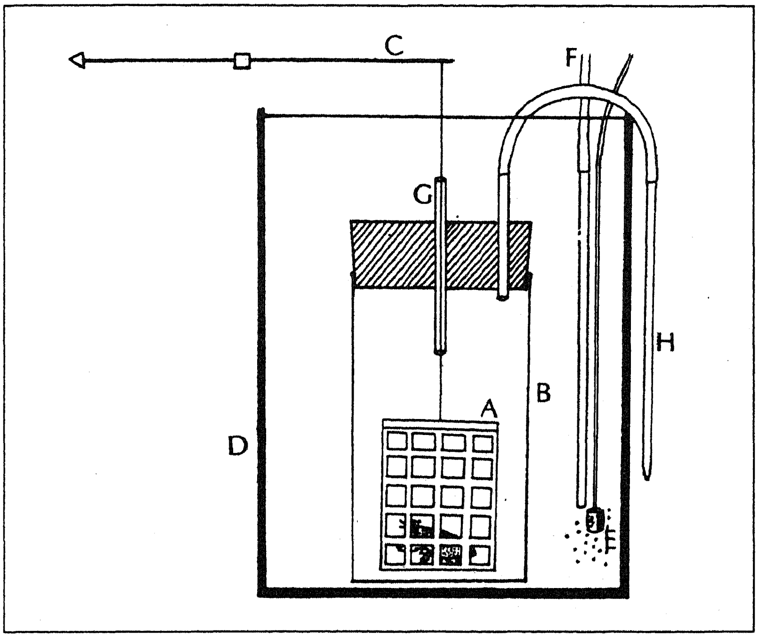


Figure 2 The simple plastic cage device used to record the locomotor activity of the crab Emerita asiatica with the continuous flow of sea water arrangement to enable oxygen consumption estimations. (A-activity cage, B-animal chamber, C-marking lever, D-constant water level trough - not drawn to size, G-inlet, H-outlet). When the crab swam up into the water space off the bottom of the activity cage, the cage rose inside the animal chamber. Such bouts of activity registered themselves through the writing stylet on the kymograph drum.

around 9 a.m. to the laboratory in the aquarium building. I had a row of continuous flow respirometers in which the respiration chamber was a wide- mouthed glass jar. One could therefore see the mole crabs. Some mornings when I came in, the crabs would swim agitatedly and on other days they sat still. The idea was to draw samples of water from the respirometers when the crabs were inactive. Since it was suspected that the movements of the investigator may cause excitement, the jars were painted over black. Then of course I could not inspect the state of activity of the crab.

I then constructed a simple but very effective actograph (*Figure 2*) with which I could continuously record the swimming activity of the crab and simultaneously measure the oxygen consumed. Dr. M J Wells was much impressed with the contraption. The recordings were traced on student kymograph drums, which, at the lowest gear, completed one revolution in 6 hours, therefore the recordings were made in several different heights, usually four. The drums had to be

adjusted at 06.00 hr, 12.00hr, 18.00hr and 00.00hr and a newly sooted drum had to be put on once every 24 hours.

I am not very clear in my mind if the events reproduced in this account truly happened the way I narrate them. But I have told this story to successive batches of M.Sc. and M.Phil candidates in this manner and have now come to believe that this is how things happened some thirty five years ago. But then, as Francis Bacon observed, "Never any knowledge was delivered in the same order it was invented".

At this stage in my research I too ought to have been in a position to shout "eureka, eureka"! But I was a victim of the condition Louis Pasteur described in the words "In the field of observation, chance only favours those minds which have been prepared".

One Monday evening I came into the aquarium at 21.00 hr for the overnight work. The day of the week matters, which is why it is mentioned. It was a new moon night and it was pitch dark, until I switched the aquarium lights on. There were twenty sea water troughs in my laboratory of about 30 cm diameter with some 4-5 cm sea water and twenty *Emerita* female crabs (ca 3-4 cm long) in each trough. These anomuram crabs have a distinctive and fascinating way of moving - burrowing backwards into the sand in the beach but always facing the sea. In laboratory troughs with water they swam backside up exposing their whitish undersides. Their carapace was slate grey. So what met my eyes were 400 crabs swimming in their troughs all around me (I tell school students 'like the host of golden daffodils dancing in the wind' when the poet saw them). This was duly noted down by me as 'lights on' effect on the crab. The activity continued and became more muted after a while. I took this to indicate some manner of 'habituation' and don't recall having given much thought to the matter for the rest of the night. But I do remember talking of the 'lights on' effect to my colleagues but none was so thrilled that he wanted to see it. Atleast not until the next Monday. A compassionate colleague, now in a university in the U.S.A., offered to stay with me for the night to see the spectacular sight. We both came to the aquarium building, again at 21.00 hr, tip-toed inside after opening the

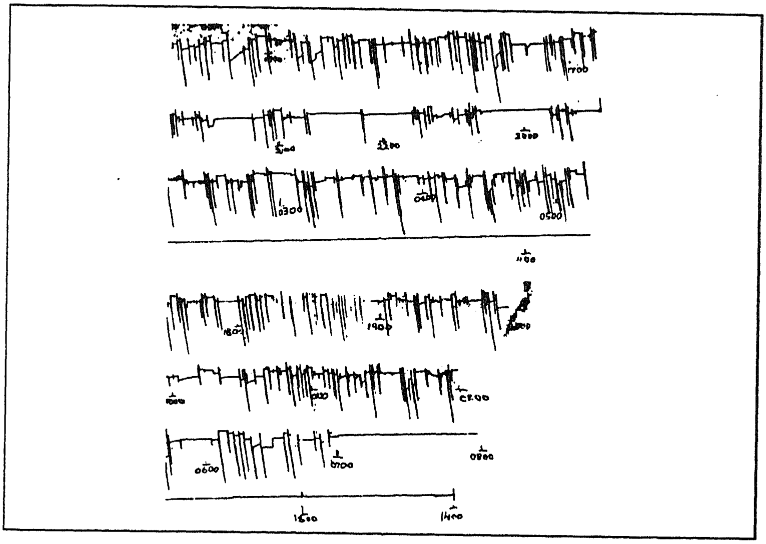


Figure 3 Typical kymograph trace indicating activity of the crab while swimming (vertical markings) and while at rest (horizontal traces).

door with bated breath, and I switched the lights 'on'. There were twenty troughs, with twenty crabs in each, and not a single crab moved! My embarrassment can be imagined. I took a pencil and touched several crabs to verify that they were alive. The crabs, thus perturbed, scampered a few cm and stayed still. A mad crab indeed.

Scientists the world over were skeptical about biological rhythms of any kind in the 1960s.

At this stage in the story, I stop to ask my students if they can guess what was happening. At this stage in my research I too ought to have been in a position to shout "eureka, eureka"! But I was a victim of the condition Louis Pasteur described in the words "In the field of observation, chance only favours those minds which have been prepared". Not only was my mind not prepared, it was set against the rediscovery of anything as fairy tale like as *tidal rhythms*. Scientists the world over were skeptical about biological rhythms of any kind in the 1960s. Fortunately for me, I had made the crabs write their own story on kymograph drums (*Figure 3*). The activity traces were 'fixed' in liquid shellac and stored away safely. I had not plotted the data. So I did not know what the mad crab was up to.

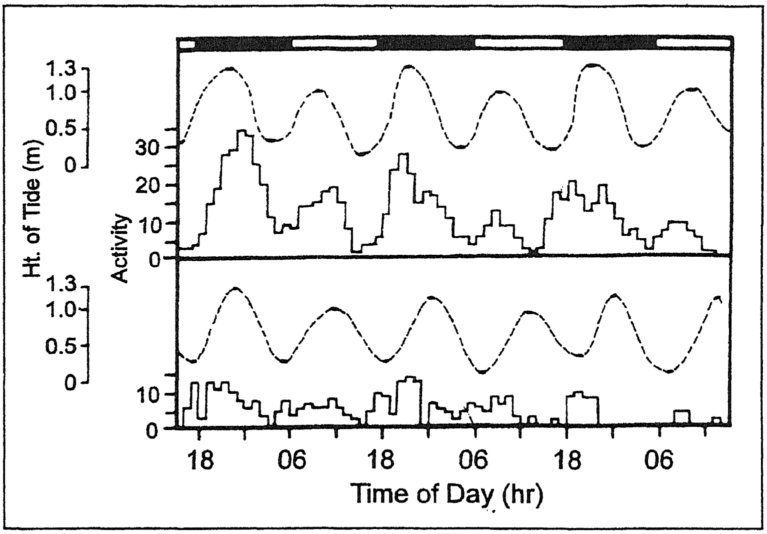


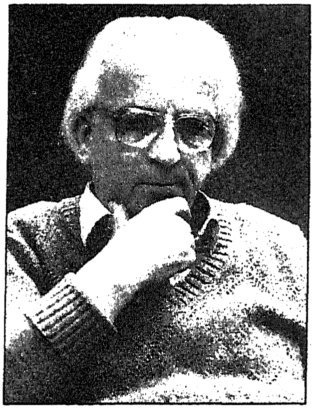
***Figure 4** Tidal rhythms in the spontaneous swimming activity of Emerita asiatica in the constant conditions of the laboratory and its waning over six days. Dark bars denote hours of darkness outside.*

Tidal Rhythms at Last!

Prof. Gnanamuthu later confided in me "between you and me, I say, I don't really believe there are rhythms".

The moment of truth dawned on me some eighteen or so months later when I decided to plot time series histograms from the swimming activity data. I was doing this late into the night and to my considerable surprise lovely and regular peaks and troughs took shape and the rhythms continued for as long as the experiments lasted! The peaks were about 12 hrs apart (*Figure 4*). During troughs the crabs had not moved for 2-3 hrs. Were these tidal rhythms?! The time was 02.00 hr. There was no one in the laboratory. Worse still we did not have a copy of the 'tide tables' published annually by the Geodetical Survey of India from Calcutta. The 'tide tables' gave in hours and minutes the times of high and low tides at various places and the heights of the tides. The first thing I did in the morning was to buy a copy of the tide tables from Lawrence and Mayo in Mount Road, rush back to the lab and draw the smooth tide curves, which filled the activity data. I breathlessly stormed into the room of Prof.Gnanamuthu and blurted out "Sir, tidal and diurnal rhythms in the activity of *Emerita!!* " or something to that effect. He also rejoiced with me and complimented me on having produced a fine piece of research.

Prof E Buenning (1906-1990).



To revert to the queer behaviour of the crabs from one Monday to another Monday. Hindsight tells me that on the first Monday it was high tide at 21.00 hr two miles away on the beach. Since the moon rises 50 min later and the lunar day is 24.8 hr, the high tide would have moved 50 min everyday over the next 7 days and been 7 x 50 = 350 min or about 6 hr later on the second Monday. This means the sea at Madras was experiencing low tide on the second Monday. The crabs on both Mondays were just reflecting or reenacting high tide (high activity) and low tide behaviour (low activity or nil activity) in the laboratory. These tidal rhythms slowly wane with time and disappear after 8-10 days of the constant conditions of the laboratory. Superimposed on this tidal rhythmicity was a nocturnal component which showed itself as exaggerated night time high tide activity. One of the tides in a semidiurnal tidal environment such as Madras must occur during hours of darkness. In the Ph.D. thesis and in my first publication (Z Vergl Physiol 1965) I did not use the word circadian which had been newly coined but used sparingly. Furthermore Prof Gnanamuthu later confided in me "between you and me, I say, I don't really believe there are rhythms". Which explains why my first paper is a single author publication. I then sent an S.O.S. to Prof. Erwin Buenning (1906-1990) with photocopies of the kymograph traces stating that no one in India wanted to believe my story, or that of the crabs. This first chronicler of chronobiology knew what I was up against and wrote back post-haste: "proceed to Tuebingen". The rest, as they say, is history.

It is true that if the tides had not moved 50 min a day, hence making my freshly captured crabs appear erratic in swimming behaviour, I might have rediscovered tidal rhythms earlier. Tidal rhythms, for the record, were first discovered in the behaviour of the flatworm *Convoluta roscoffensis* (Turbellaria) by C Bohn in 1904. The moral of the story may also be: you don't discover any kind of rhythms if you work 9 to 5.

Suggested Reading

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Nature Watch

A Horde of Indian Deer

T R Shankar Raman

T R Shankar Raman studied the ecology and breeding seasonality of chital for three years in Guindy National Park. Interested in natural history and conservation, he later went on to study the impact of shifting cultivation on wildlife in the tropical rainforests of Mizoram, northeast India.

Deer are some of the commonest, most visible, and attractive mammals in many forests and grasslands of India. They display a fascinating variety in their antlers, social systems, herd-forming behaviour, and ecology. Unfortunately, several factors have brought some species to the brink of extinction today.

The loud, throaty bellow of the chital stag resounded through the fresh morning air. Hidden behind a few trees and bushes, I watched silently as it stood on an open grassland near a small herd of chital does and their young fawns. Further away, there were two other herds of deer. One herd had larger animals than the other and comprised about a dozen individuals. Their tawny, orange-tinted coat, and the highly-branched antlers of the males in the herd, indicated that this was a herd of swamp deer or barasingha. The second herd was a group of three hog deer grazing at the edge of a patch of tall grass. From that particular vantage point in Dudhwa Tiger Reserve, I could thus observe, at a glance, three species of deer. But this was not all. Later that day, I saw two more species, the sambar and the barking deer, in the dense sal forests within the sanctuary. Dudhwa, on the Indo-Nepal border in Uttar Pradesh, is one of the few places where one can observe, even today, five of India's eight deer species (*Box 1*). The Indian sub-continent has an unusual bounty of deer species, each unique in appearance, ecology, behaviour, and geographical distribution.

The Indian sub-continent has an unusual bounty of deer species, each unique in appearance, ecology, behaviour, and geographical distribution.

How Many Deer?

Deer belong to the group of herbivorous, hoofed mammals or ungulates called artiodactyls, which includes camels, pigs, antelope, cattle, and hippopotamuses. The deer are characterised by an even number of toes, the presence of antlers (bony outgrowths of the frontal bones of the skull) in males of most species, and a four-chambered stomach. Of the 40 existing deer species in the world, nine occur in India, of which the true deer or cervids (Family: Cervidae) account for eight species (see below).

Class: Mammalia; **Order:** Artiodactyla

Family: Tragulidae

1. Indian mouse deer ***(Tragulus meminna)***

Family: Cervidae

Sub-family: Cervinae

1. Chital or Axis deer (***Axis axis***)
2. Hog Deer (***A. porcinus***)
3. Swamp deer or Barasingha (***Cervus duvauceli***)
4. Hangul or Kashmir Stag (***C. elaphus hanglu***)
5. Sangai or Manipur brow-antlered deer (***C. eldi eldi***)
6. Sambar (***C. unicolor***)

Sub-family: Muntiacinae

7. Muntjac or Barking deer (***Muntiacus muntjak***)

Sub-family: Moschinae

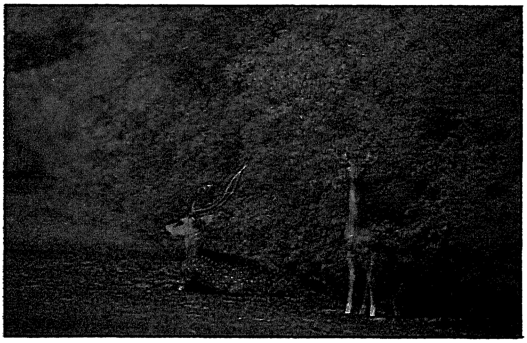
8. Himalayan musk deer (***Moschus moschiferus***)

A Head for Courtship and Combat

A characteristic of the deer, that strikes an observer watching a herd, is the pair of branching antlers on the heads of some individuals. Males of most deer species carry antlers, which are often mistaken for horns (*Box 2*). The growth and development of antlers plays a major role in the life cycle and reproductive behaviour of deer. In the chital or spotted deer, the first pair of antlers appears from stub-like pedicels on the head,

Figure 1 (a) (bottom left) An adult chital male (stag) with growing antlers in velvet;

(b) (bottom right) An adult stag with mature hard antlers rests at a forest edge beside a watchful female (doe).



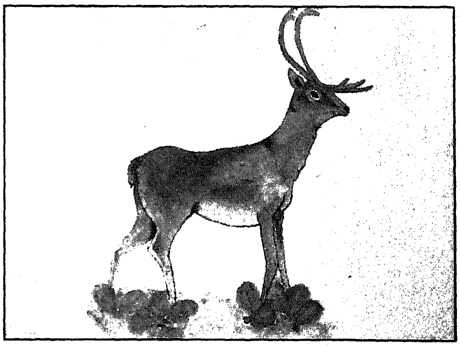
What is an antler?

Antlers occur in 36 of the 40 existing deer species in the world. Three species of musk deer (***Moschus spp.***) and the Chinese water deer (***Hydropotes inermis***) lack antlers. Antlers are different from horns that other ungulates such as buffaloes, antelopes, goats, and sheep have. Unlike horns, antlers are composed of bone and not keratin, and they are shed and regrown every year, whereas horns grow continuously throughout the life of the animal. Antlers are mainly used in serious and playful fights between males, though they may also play a role as status symbols that indicate dominance. Antlers occur only in males, except in the reindeer (***Rangifer tarandus***), where even females carry them. Female reindeer attain hard antlers in winter when males are in the vulnerable velvet antler stage. They use their antlers to ward off males that compete with them for food in their cold tundra habitat in North America and Eurasia.

when the male is almost a year old. These antlers grow to be simple and spike-like, about ten centimetres long. The following year, as the male grows in body size, these antlers are cast off (shed) from the pedicels. A new pair of antlers begins to grow, attaining a final length of 25-30 centimetres in a few months. This process of shedding antlers and growing new ones recurs annually, and the antler size increases roughly in proportion to the animal's age.

A layer of skin and hair, called the 'velvet', richly supplied by blood vessels, covers the growing antlers (*Figure 1a*). With the onset of the breeding season, the levels of the male hormone testosterone increase in the blood, and the antler undergoes mineralization (calcification). The velvet gradually peels off, or the male rubs it off on shrubs and branches. This exposes

Figure 2 (bottom left) Two hardground barasingha stags in a parallel-walk aggressive display.



Painting by Sumana Rao

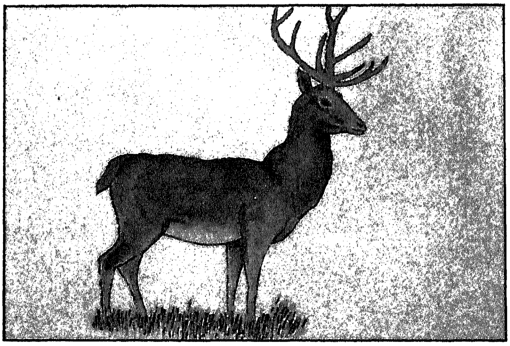
Figure 3 (bottom right) The Manipur brow-antlered deer or dancing deer occurs only in the marshy habitat with floating islands in Keibul Lamjao Sanctuary.

the underlying bony, hard antler *(Figure 1b)*. The antler of an adult has a branch called the *brow tine* (emerging just above the pedicel and curving forwards and upwards) and the *main tine* or *beam*. The main beam again branches at the top to produce the *bez* branch. In other deer, such as the barasingha, there may be a further *trez* branch and many tines, giving it a highly-branched appearance (Hindi: *bara* - twelve, *singha* - branches; *Figure 2*). The antler of the Manipur brow-antlered deer is peculiar, as the brow tine and main beam form a continuous, sweeping arc over the head (*Figure 3*).

The time of year when most adult males are in hard antler, forms the peak of the breeding season or rut. The peak rut differs according to the species. Over most of India, adult chital stags attain hard antlers between April and June, whereas sambar rut during the winter (*Figure 4*). Spurred by the testosterone, the neck and body muscles develop, making the animals appear larger than usual. Males begin to rove widely in search of oestrous females and court them avidly. In other deer, such as the swamp deer or barasingha and the Kashmir stag or hangul (*Figure 5*), males defend territories during the breeding season. By means of displays such as roaring and herding, they attempt to attract females to their territory and guard their harem jealously from other males. The females may not be mere passive spectators of male prowess; anecdotal observations suggest that females actively choose the males they mate with.

Figure 4 (bottom left) An adult sambar female at a waterhole raises her tail - a characteristic alarm posture of many deer species.

Figure 5 (bottom right) The Kashmir stag or hangul population is today confined to Dachigam sanctuary in Kashmir.



Painting by Sumana Rao

In the more primitive deer, such as the Himalayan musk deer and the barking deer or muntjac (*Figures 6 and 7*), the male secondary sexual characteristics and breeding systems are different. Musk deer and muntjac are forest-dwelling, relatively sedentary, and territorial species. The musk deer lack antlers, but instead carry a pair of nasty-looking tusks, which are merely the elongated upper canines of the males. Muntjac males also have tusks but, in addition, carry a pair of small, spike-like antlers on their head, often with only a small protuberance representing the brow tine. They are therefore considered an intermediate form between the primitive deer that lack antlers and the more advanced cervids, such as the chital or barasingha.

Figure 6 (bottom left) A musk deer male, with its dagger-like upper canines (tusks), at a feeding site in a captive breeding facility in Kedarnath sanctuary. The deer are being bred for reintro- duction into the wild.

Figure 7 (bottom right) A female muntjac or barking deer. The deer are named after their characteristic alarm call, which is a loud bark.

Bones of Contention

Males use their antlers for playful or serious combat with each other. Being hard, bony, and not covered by any soft tissue, the antlers are less prone to undue damage when males interlock, shove, and clash against each other. Broken antlers do result at times, but these can be shed at the end of the season, and new ones grown the following year. Biologists have proposed that antler casting may have evolved to enable such repair. This way, antler size can also increase in tandem with body size.

Actual combat is infrequent compared to the number of occasions when there is some form of aggressive (antagonistic) interaction between males. This is because each species of

K Surendra Varman

Figure 8 The hog deer is a specialised species of the tall grasslands, called the terai, in the Ganges and Brahmaputra flood plains .

evolved certain characteristic assessment displays by ıales size-up each other before combat. Roaring rates, d antler size, and parallel walks are displays of this *gure 2*). After males have several such encounters with nales, they establish a dominance hierarchy or ler. Subordinate individuals learn to avoid or merely ·fully with dominants. Serious fights do occur, however, males that are almost evenly matched, and may lead to life-long injury.

n for Fawns

result of the competition and courtship during the g season is the annual crop of fawns. In most deer females give birth to fawns during the season when ›urces are abundant. Thus, hog deer in wet grasslands fawn mostly during April and May when, after the d the pre-monsoon showers, there is a flush of new routs (*Figure 8*). In contrast, chital, which are close of hog deer, produce most fawns between December ch, during the onset of the dry season. It is not clear y do this. Perhaps, this helps the chital does to their energetically-expensive late-lactation period onset of rains and flush in food availability in May e. It also entails pregnancy during the wet season,

Herding or group-forming behaviour is a characteristic of many ungulates or hoofed mammals, including several species of deer.

enabling does to meet the needs of the developing embryo, while storing resources for the following dry season. When the fawns are born, they are usually kept in hiding for a few days or weeks as they are vulnerable to predators. Soon the fawn begins to follow its mother; gradually, it also learns to forage on its own after weaning. During the fawning season, one can commonly see small herds of does and fawns forming and foraging together. The tendency to form herds varies, however, with the social system and the habitat of the species.

The Herd Mentality

Herding or group-forming behaviour is a characteristic of many ungulates or hoofed mammals, including several species of deer. Some species, such as the small, forest-dwelling musk deer and muntjac, occur solitarily or in pairs male-female or female-young pairs. Other species, such as the chital and barasingha form large herds of a hundred individuals or more. Usually, forest species form smaller herds compared to species of open grasslands or the forest-grassland interface. In chital, average herd sizes vary widely in different months of the year, from about two to over thirty or so individuals. Groups of a hundred or more individuals occur sometimes during the wet season. In scrub and grassland habitats, herd size and density of chital directly relates to the amount of rainfall and grass growth.

On detecting predators, large males often muscle their way to a secure position in the centre of the herd, leaving the females and the young on the periphery. So much for chivalry in the species !

Besides the availability and dispersion of food items, the need for safety in numbers influences herd size when facing predators. Larger herds can detect predators earlier as many animals are simultaneously watchful. On detecting predators, such as a pack of wild dogs, a large herd of chital will often bunch up into a compact group and face the predator. They give calls and stamp their feet on the ground in alarm (glands between the digits of the feet deposit a substance that serves as a warning). In such a situation, large males often muscle their way to a secure position in the centre of the herd, leaving the females and young on the periphery. So much for

chivalry in the species! While predators do take a regular toll of individuals, there are more potent threats to the survival of deer, and many species are today at the brink of extinction.

Poised on the Brink

Several aspects of deer biology have contributed to the precarious position that some species are in today. Species such as the swamp deer and the hog deer (*Figures 2 and 8*), being specialized to grassland habitats, have suffered from habitat loss to agriculture and development activities. Three subspecies of swamp deer exist today, all critically endangered: the hardground barasingha of Central India (*C. duvauceli branderi*); and the swamp subspecies (*C. d. duvauceli* in Northern India and *C. d. ranjitsinhji* in Eastern India). Several thousand hardground barasingha probably existed in the Central Highlands of India, in grassland habitats along the Vindhya and Satpura hill ranges. Hunting and loss of their habitat brought down their numbers drastically this century, until in 1970, only 66 survived in Kanha Tiger Reserve in Madhya Pradesh. After ecologists attracted attention to the hardground barasingha's plight, wildlife managers took several restorative measures, including the relocation of villagers occupying and cultivating some grassland areas. The species appeared to respond positively to these measures and, within a decade, there were about 280 animals again at Kanha. The swamp subspecies of the barasingha occurs in the unique, marshy, tall grassland habitat, called the *terai*, along the Indo-Gangetic and Brahmaputra plains. This habitat occurs today in a few sanctuaries and protected areas in Uttar Pradesh, Nepal, West Bengal, and Assam. Similar threats as faced by the hardground barasingha and hog deer have contributed to the decline of these subspecies in north and east India.

Species such as the swamp deer and the hog deer being specialized to grassland habitats, have suffered from habitat loss to agriculture and development activities.

The swamp subspecies of the barasingha occurs in the unique, marshy, tall grassland habitat, called the *terai*, along the Indo-Gangetic and Brahmaputra plains.

The Manipur brow-antlered deer, also called the sangai or thamin, is perhaps the most endangered subspecies of deer in the world.

Two other deer species occur in single, isolated, protected areas, hovering at the brink of extinction in the wild. These are the Kashmir stag or hangul (Figure 5) and the Manipur brow-antlered deer (Figure 3). A combination of habitat loss and hunting for trophies and meat has reduced them to this plight. The hangul is a subspecies of the European red deer. Another subspecies that occurred in the eastern Himalayas, the Sikkim stag or shou, is now perhaps extinct. From over 2,000 hangul that existed around 1947, probably less than 300 exist today in a single sanctuary. This sanctuary, Dachigam, was reserved as a game preserve by the last Maharaja of Kashmir, Hari Singh, and today occupies some 141 km^2 in the Kashmir Himalayas. The hangul population thrives in subtropical forests, migrating between the higher slopes of the mountains and the autumn rutting grounds in the main Dachigam valley.

The Manipur brow-antlered deer, also called the sangai or thamin, is perhaps the most endangered subspecies of deer in the world. Its population declined from about 100 individuals in 1959 to only 20 individuals or so in two decades. Today, the only existing wild population occurs in the Manipur valley of northeast India, occupying a very peculiar habitat in Keibul Lamjao Sanctuary, a part of the Logtak lake. Many floating islands, called the *phum* or *phumdi*, occur in this marshy habitat. The *phumdi* is a mass of decaying organic matter about one to four feet in depth. It floats on water during the wet season, and settles on hard ground when water levels fall. Sangai have modified, split hooves that enable them to move over the floating vegetation with a fluid gait that has earned them the name dancing deer. There are substantial numbers of this deer in captivity in various zoos today. Conservationists have therefore suggested establishing free-ranging populations in other areas using captive stock. This can stave off the threat of extinction, which can speedily dispose of a single, small population.

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Another endangered species is the Himalayan musk deer. The species is famous for the aromatic musk, contained in a pouch under the male's abdomen. As musk is costlier than gold by weight in today's markets, it attracts poachers who hunt and trap the deer. Often, females and young ones are also trapped in snares, taking a heavy toll of the species. Today, the law protects the musk deer and programmes for captive breeding and re-introduction of the species in the wild are in the offing (*Figure 6*).

India is fortunate to have such a diverse array of deer species, ranging from the small musk deer to the huge sambar, occupying a variety of habitats. For thousands of years, they have thrived in India as an essential component of various ecosystems. Today, their future appears uncertain. Will the hangul, the hog deer, the sangai, and the barasingha vanish like the Sikkim stag? Or will conservation efforts enable them to persist through the next century? While we can only guess the answers, it is certain that if these species disappear, India's forests and grasslands will lose an irreplaceable element of their charm.

Suggested Reading

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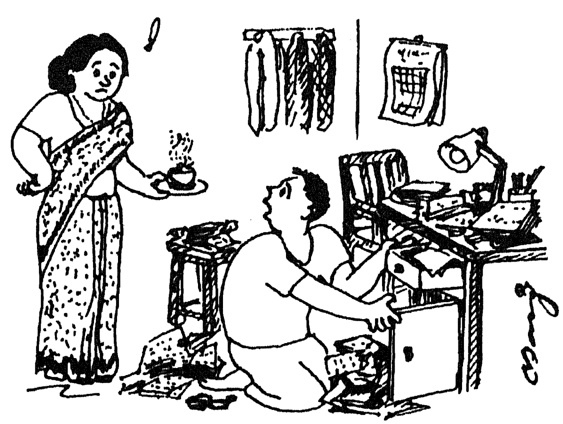

Did you see that book "MEMORY IMPROVEMENT TECHNIQUES" I have been reading yesterday ?

Molecule of the Month

A Tetrahedrane Derivative

Uday Maitra

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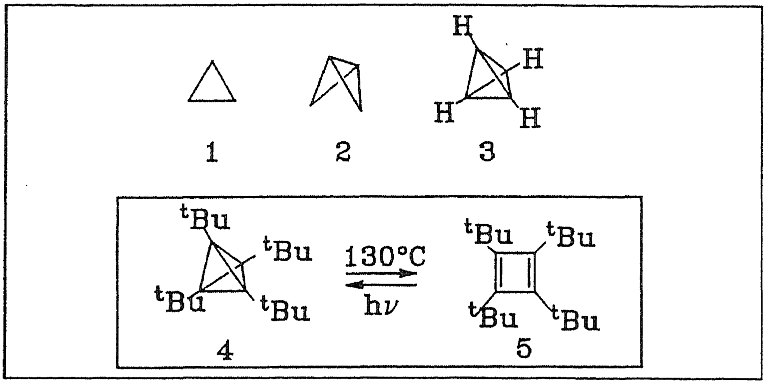
Studies on a highly strained hydrocarbon are discussed.

Atoms in a molecule generally prefer, particularly among the neighbouring ones, certain optimum geometrical relationships. These are manifested in specific ranges of bond lengths, bond angles, torsion angles etc. As it always happens, chemists are interested in making molecules where these 'standard relationships' are violated! Such molecules, by virtue of their altered bond lengths, bond angles, or torsion angles, store a lot of strain within the molecule. For example, whereas propane ($CH_3CH_2CH_3$) is virtually strain-free, cyclopropane (**1**) is highly strained, because of the deviation of the bond angles ($<$CCC) from the normal value of 109.5°. If you put two cyclopropane rings together, as in compound **2** (known as bicyclo [1.1.0] butane), the strain energy more than doubles. One molecule that has interested chemists for many decades is **3** which can be derived from **2** (remove two hydrogens, and make an additional carbon- carbon bond). This (hypothetical) molecule has been named *tetrahedrane*, and is the smallest molecule with the general formula $(CH)_n$ without a double bond. It has four carbons arranged at the vertices of a regular tetrahedron, with each carbon being bonded to the other three, and to one hydrogen. This small but beautiful molecule has been the synthetic target of many chemists, but all attempts to generate it failed. Why? The answer is rather simple! If we compute the strain energy of **3**, and compare it with **2** we can easily see that tetrahedrane is about as strained as two molecules of **2**! This much strain leads to thermodynamical instability. Thus, such high energy molecules will always decompose to produce more stable molecules, in that process



releasing the strain energy (just like releasing a compressed spring). Thus, compound 3 can in principle decompose to other $(CH)_n$ molecules (such as a molecule of cyclobutadiene which would in turn dimerize to form cyclooctatetraene, or fragment to two molecules of acetylene) which do not have as much strain.

Going by these theories, it seems that the construction of a molecule such as **3** would be an impossible task! However, there is usually a way out of the thermodynamic instability. Even when a process is highly favourable thermodynamically, it may be kinetically slow. Once again, we can find an analogy with a compressed spring, kept in a container too small to let it expand. The highly thermodynamically favourable, but kinetically slow, reaction $2H_2 + O_2 \rightarrow 2H_2O$ is an example closer to this. How does this idea help chemists design a stable tetrahedrane analog? The approach taken by Günther Maier and coworkers is simple in principle. They decided to substitute the four hydrogens of **3** with bulky tertiary butyl groups. In compound **4** , these groups are as far apart from each other as possible compared to any other C_4 framework. Thus, any attempt by compound **4** to become a cyclobutadiene unit will be resisted because that process will bring the big t-butyl groups too close to each other causing van der Waals' repulsion. Thus, compound **4** seems to be the right choice to make the tetrahedrane skeleton. Chemists generally employ another trick to make high energy molecules. It is usually easier to put in the extra energy (which appears as the strain energy) in the form of

Even when a process is highly favourable thermodynamically it may be kinetically slow.

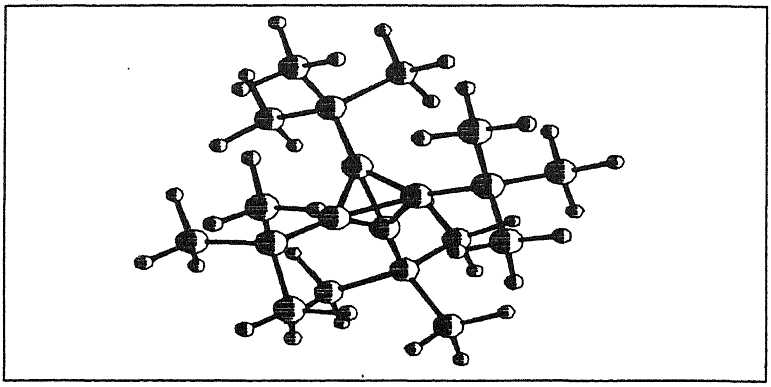


Figure 1 Ball and stick representation of tetrahedrane derivative 4

light. In other words, photochemical processes are ideally suited for constructing high-energy molecules. That is indeed how compound 4 was successfully synthesized in about 35% yield by a photochemical route (see Figure 1 for a ball and stick representation of compound 4). This molecule was found to be a colourless solid melting at 135°C! It was also found that heating compound 4 at 130°C slowly converted it to the yellow-orange cyclobutadiene derivative 5. But 5, upon photochemical irradiation, may be converted back to 4. This interconversion clearly points out the kinetic stability of 4. A space filling model (not shown) of 4 clearly shows the tetrahedron skeleton well-covered by four t-butyl groups.

These studies show that even seemingly unstable molecules can be stabilized by making their path to destruction (reaction) inaccessible!

In 1984, Maier was successful in obtaining the crystal structure of tetrahedrane 4. Interestingly, it was found that the C-C bond distance within the tetrahedron skeleton was shorter (1.485 Å) than a normal C-C bond (1.54 Å).

These studies therefore show that even seemingly unstable molecules can be stabilized by making their path to destruction (reaction) inaccessible! Readers may be interested to learn that a similar tetra t-butyl substituted ethylene has not been made so far.

If any of our readers is interested in learning how compound 4 was synthesized, (s)he is welcome to write to me for the details.

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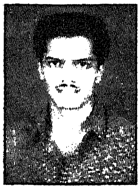
What's New in Computers

The Web PC

Vijnan Shastri

The Web PC might dramatically change computers as we know them! But, is it really feasible? Read on, to understand the pros/cons of the issue.



Vijnan Shastri works at the Centre for Electronics Design Technology in the Indian Institute of Science, Bangalore, and his areas of interest are digital and microprocessor systems, storage subsystems and systems software.

There's a lot of discussion today about the internet, the World Wide Web that is used on the net and the way it might alter desktop computing. The Web is expected to spawn many application and technology areas, both in software (Java is an example) and in hardware. In hardware, there is now a raging debate as to whether the PC as we know it will cease to exist in the coming years - to be replaced by the Web PC. Other names for this are the Web terminal, network computer, internet appliance etc. The debate, apart from technological reasons has important commercial implications as well. We'll see what this is all about in the following paragraphs.

In its more than decade-old existence, the PC has managed to adapt to technological changes such as improved processor speed and storage capacity and take on new software operating environments such as Windows 95. Every time the death-knell was sounded for the PC, the designers tweaked with the architecture, came up with improved standards (such as the EISA improved Extended Industry Standard Architecture and the PCI - Peripheral Component Interconnect bus), gave it new capabilities such as the ability to handle multimedia and high speed graphics and the PC got yet another lease of life for a few more years. This of course was possible with matching increase in the capability of PC based peripherals such as displays, hard disks and CD-ROM drives. Above all, the PC is affordable and most important,

The growing complexity of PCs and their susceptibility to virus attacks makes maintenance and management of these systems a costly affair. This is the starting point of the argument for a WebPC.

one can get very sophisticated software at reasonable prices. The PC and the availability of relatively cheap software has also made it possible for computer technology to be pervasive as opposed to being costly and restricted to high performance machines. Moreover, today, the dividing line between Pentium class PCs and low-end workstations is very hard to define. Keep in mind that these PCs offer a lot more functionality and their cost (hardware + software) is a fraction of that of a workstation. PCs are also able to talk to each other through the telephone lines, send faxes and email and login to information servers through the internet in any part of the globe, all this of course at low transfer speeds. While these are all the positive developments, there are serious negative aspects to PC's.

Small LANs have become extremely popular even in very small organizations. Many of these LANS consist of PCs (clients) and a central file server which holds all the software and 'serves' the software to the clients on-demand. This makes the need for large hard disks on PCs, redundant. Further, PCs need to be constantly upgraded with hardware components (such as the motherboard, hard disk, display) and this is a continuous financial burden on the user. Add to this the cost of constantly upgrading the software.

Given that many PCs operate in a LAN environment, the operating system residing in these machines is not only unnecessarily bulky (like Windows 95) but is also (again unnecessarily) duplicated in each of the PCs. This is also true for application software and as a result makes it necessary to have large hard disks on each of the PCs. The growing complexity of PCs and their susceptibility to virus attacks makes maintenance and management of these systems a costly affair. This is the starting point for an argument for the WebPC.

The two important assumptions that proponents of the WebPC make are:

- A high speed network is available
- There are enough powerful machines on that network, to not only 'serve' all the software but to be capable of powerful computations as well.

The following would be the characteristics (*See Figure 1*) of a typical WebPC.

- A low-cost RISC microprocessor.
- No local hard disc or a very small one if it exists.
- High resolution display capability.
- High speed network connectivity (at least 25 Mbits per second)
- Will run a simple Operating System (referred to as a 'lightweight' OS)
- Will have a Java interpreter
- Optionally will have Video and Audio decoding capability, plug-ins for CD-ROM drives and hard disks.
- Will cost (its promoters claim) less than $500.

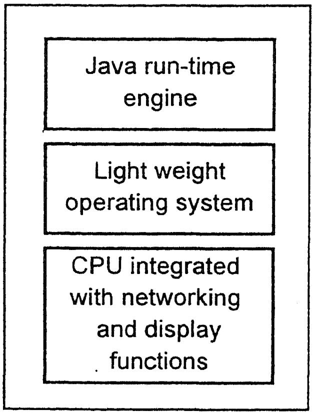


Figure 1 Components of a WebPC

Those familiar with the X-terminal can immediately find similarities with the WebPC .

The plus points of the PC

- Relatively cheap and powerful environment.
- A myriad variety of software is available, giving it a lot of functionality and making it tunable to the needs of the user.
- User can choose a configuration (hardware) and buy software that suits his pocket, yet achieve results.
- It is independent - and does not depend on any other machine for its operation. This gives the user the freedom to use it the way she likes.
- Since it has been around for a long time, there is a lot of PC trained human resources available.

The minus points

- Has to be constantly upgraded - both hardware and software, thus imposing a financial burden on the user.
- Maintenance can be complicated and expensive.
- Susceptible to virus attacks.
- Operating systems and applications are bulky, unnecessarily so for a large number of users. Further, they require large hard disks and maintenance skills from the user.
- Do not take advantage of high speed networks (if available).

The plus points of the WebPC	The minus points
• Will be a very cheap (under $500), simple 'terminal' kind of device. • Will entail almost no management / configuration headaches for the user. • Will not have to be upgraded frequently. • Software upgradation is not an issue since it is handled on the central server. Immediately applicable within organizations with high speed LANs	• Assumes the existence of a high speed communication network at every desktop - this is an unlikely scenario in the near future. • Management of huge centralized servers requires enormous investments. • Concentrates power in the hands of a few due to centralized server approach.

The Java environment (the Java language was discussed in ***Resonance*** Vol. 1, No. 5, 1996), which is one of the key issues in the WebPC, assumes that an application is divided into components. These components called applets will be downloaded (from a remote server) by the WebPC into its RAM only on an on-demand basis. This is in contrast to today's PCs which load the entire application into memory from the local hard disk. This entails that the PC be equipped with large amounts of RAM . Many parts of this application may not be used at all during the session. Take the example of a typical word processor running on Windows. The entire package consisting of the formatting tools, drawing tools, spell checker etc. is loaded into memory. The WebPC on the other hand will load these tools (implemented as applets) only on an on-demand basis from the remote server. A similar concept exists for the PC environment and this type of software is called 'component-ware'.

Application components in Java will be downloaded by the WebPC only on an on-demand basis. This is in contrast to today's PCs which load the entire application into memory from the local hard disk.

Since the demands on the WebPC in terms of capabilities are low, the user will not have to worry about upgrading it as often as he/she did with the PC. Due to the simple structure, maintenance costs will be very low. Furthermore the Java environment moves the burden of maintenance and configuration of software to the server - away from the user with the result that administration costs at the user-end are

virtually zero. Software upgradation for instance, needs to be done only on the server before one uses the new version (after paying the costs of course!). Will the Web PC really replace the desktop PC? There are many questions both technological and economic which need to be addressed before we decide the future of the WebPC.

The WebPC can succeed at an organizational level where high speed LANs are already in place. WebPC protagonists hope that this environment together with the rapid acceptance of Java will be the 'launching pad' for the WebPC.

The first assumption made in the WebPC environment, that high speed networks will reach every desktop, is 'easier said than done'. It requires huge investments in terms of capital costs and it is technologically a mammoth task to install high speed networking switches and communication links to handle all the data demands of the WebPC on every desktop. Although speeds of communication networks are increasing by the day, it will take a while before they reach speeds demanded by the WebPC.

Many have doubts if the WebPC hardware can be built at a cost under $500. Unless the price is of this order of magnitude users would not think of replacing their existing PCs. Since the WebPC will have only a Java interpreter (vs. running compiled code on a PC) and hence will be inherently slow, many doubt that enough computing power can be packed into it at this price. With 3-D graphics applications becoming a reality in the coming years, this will place phenomenal computing burdens on the servers and also result in data traffic on the network. There is also the issue of network security: since the WebPC relies on a centralized system, a computer hacker can create total chaos for a large number of users if he manages to break-in. This is unlike the PC where the virus (although communicated through floppies or networks) attacks only the PC on which it (the virus) is running. One will have to develop Java applications with capabilities better than the PC-based applications. There is also the issue of the portable PC market which is growing at a very fast pace. It is unlikely the WebPC can make a dent in the portable market in the near future since high speed wireless

The WebPC relies on the central computing paradigm (with its political ramifications) whereas the PC is of a distributed computing nature.

connections is a concept far into the future. The cost of installing and running the servers also cannot be ignored.

However where the WebPC can succeed is at an organizational level where high speed LANs are already in place. WebPC protagonists hope that this environment together with the rapid acceptance of Java will be the 'launching pad' for the WebPC. Commercial companies like Sun and Oracle, backed by IBM, have come up with the concept of the WebPC and are promoting it strongly. Sun has a strong presence in the workstation market and Oracle in the database market. Microsoft is perceived to be anti-WebPC since it has a lot at stake in the PC market. Microsoft's competitors also regard this as an opportunity to break the dominance of Microsoft over the PC market.

In developing countries, where communication networks are very poor, the PC certainly appears to be a better solution to solve computing problems (albeit partially) since it can be distributed and one can build machines with the not-so-latest hardware and software and yet achieve some results. Also, communication links to international networks are very expensive and only a handful of organizations have this facility today. In some sense the WebPC relies on the central computing paradigm (with its political ramifications) whereas the PC is of a distributed computing nature.

In this article we have tried to examine the major issues behind the concept of the WebPC. Like all products in the information technology arena, the success or failure of the WebPC will depend on the response of the market-place rather than the technology alone.

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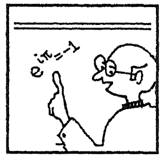
Suggested Reading

The Bill Gates interview. ***Economic Times,*** **December 11, 1995.**

Tom R Halfhill. Inside the Web PC. ***Byte Magazine,*** **March 1996.**



In this section of Resonance, *we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.*

! The Multidimensional Drunkard

From The Problems of Mathematics, by Ian Stewart, pages 185-187, Oxford University Press (1992).

Among the things probabilists study are *stochastic processes*. Here a system of some kind sits in some particular state, and at each instant the state changes randomly according to some specified set of probabilities...........

The simplest such process is the one-dimensional *random walk*. Imagine a line, marked off in units. At time 0 a particle starts at position 0. At time 1 a coin is tossed: if the coin comes up heads the particle moves one unit to the right; if tails, one unit to the left. At time 2 this process is repeated, and so on. Assuming the coin to be fair, the *transition probabilities*, for motion right or left, are 1/2 at each stage. We ask what the long-term behaviour of this system looks like. Will the particle wander off along the line, or hover about near the origin, or what? Since it has equal chances of going either way, it doesn't seem especially likely that it will wander away for good; on the other hand, there is little to prevent it drifting quite a way along the line, because every so often a run of unusually many heads or tails will occur. In other words, we expect its position to fluctuate in a pretty irregular fashion, not moving too fast on average, but with a fair chance of eventually getting to pretty much any point on the line. And indeed that's

Drunkard : Will I ever, ever get home again?
Polya : You can't miss, just keep going and stay out of 3D!
From Gerold Adam and Max Delbrück. Reduction in dimensionality of biological diffusion processes, in Structural Chemistry and Molecular Biology, (Edns) N Davidson and A Rich, W H Freeman, San Francisco, 1968.

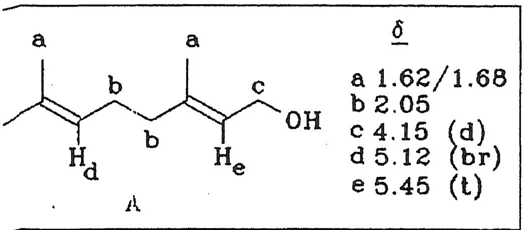
what happens. Given *any* point, however far away from the origin, the probability that the particle will eventually reach that point is 1. Or, putting it another way, the chance that it *never* reaches the chosen point is 0. Indeed, with probability 1 it returns infinitely often to the point. The motion is smeared into 'uniform' fluctuations over the whole line.

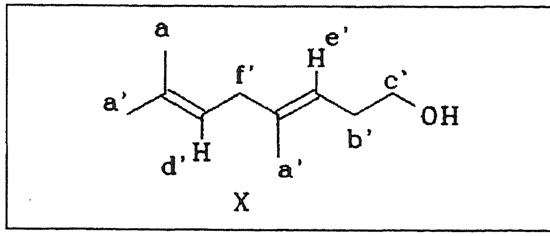
So, if you are lost in a 1-dimensional desert, and go East or West by repeatedly tossing a coin, you will eventually reach any point you wish. But there's a price to pay: it takes a very long time. In fact the time is so long that the *average* time between successive returns to the same point is infinite. If you perform a similar random walk, but now move in the plane, with probabilities 1/4 of going East, West, North, or South, the results are very similar. If you are lost in a 2-dimensional desert, you still expect to reach every point eventually by moving at random in each of the four directions. What about three dimensions? Now you can go up and down as well, with all transition probabilities being 1/6. In 1921 George Pólya proved that the results are very different: there is a non-zero probability (about 0.65) that you *never* reach your chosen position, however long you walk.

From Uday Maitra, Indian Institute of Science, Bangalore.

! Distinguishing Isomers by NMR Analysis

Our readers may recall that in the January, 1996 issue of ***Resonance*** NR Krishnaswamy discussed in detail how the structure of a natural product may be determined through a combination of chemical and spectroscopic methods. In particular, the use of ^{1}H-NMR spectral analysis for the assignment of the structure of geraniol (A) was illustrated (page 60, *Scheme 2*). S V Eswaran (St. Stephen's College, New Delhi) has asked if the NMR data provided are consistent with any other structure (for example, X). This is an interesting question. It is highly desirable to show that the spectral data support the proposed structure and at the same time are inconsistent with alternative structures.





en though structure X satisfies the general conclusions ;gested by the NMR analysis such as the presence of three thyl groups, two olefinic hydrogens etc., the precise position of : NMR signals (δ values) and the multiplicities are very different these two isomeric molecules. Specifically, the CH_2OH signal in npound X would appear as a triplet, and not as a doublet as is ;erved. Similarly, signal c′ would be expected to be upfield en compared with c (since c is allylic and next to the OH ›up). Signal f′ would also be expected to be more downfield n b (as it is doubly allylic) and would appear as a doublet.

is discussion in fact illustrates that even two closely related ıctures can often be distinguished by NMR spectroscopy, ough a careful analysis of the positions (δ values) and the .ltiplicities (singlet, doublet etc.). [There are further nplications possible here because of the presence of the OH ›up, but we have assumed that the OH hydrogen is NOT ıpled to the hydrogens on the neighbouring carbon atom. We 'e also ignored long range (allylic) couplings].

ere were a few errors in the δ values reported for geraniol in original article. The corrected values are shown here. wever, these errors do not affect the general conclusions. There ;, on the other hand, a more serious typographical mixup of the nes of geraniol/geranial and nerol/neral towards the end of s article. This sentence should read: "However, upon dation, both geraniol and nerol give a mixture of aldehydes ral) which is an inseparable mixture of geranial and neral". We ret the confusion caused by these errors.

Think It Over

This section of Resonance is meant to raise thought-provoking, interesting, or just plain brain teasing questions every month, and discuss answers a few months later. Readers are welcome to send in suggestions for such questions, solutions to questions already posed, comments on the solutions discussed in the journal, etc. to Resonance, Indian Academy of Sciences, Bangalore 560 080, with "Think It Over" written on the cover or card to help us sort the correspondence. Due to limitations of space, it may not be possible to use all the material received. However, the coordinators of this section (currently A Sitaram and R Nityananda) will try and select items which best illustrate various ideas and concepts, for inclusion in this section.

From : Rahmat Yousuf-zai, Reader in Urdu, University of Hyderabad

1 100kg with Five Stones

A grocery shopkeeper keeps five stones of different weights. He is able to use a common balance and weigh out quantities ranging from 1 to 100 kg, in steps of 1 kg. What are the weights of these five stones?

2 Finding the Odd Ball

There are twelve balls of the same colour and size but one ball is different in weight. It is not known whether this defective ball is heavier or lighter than the others. You are given a common balance and no weights. You can use the balance only three times. Find out which ball is defective and whether it weighs less or more than the others.

3 The Dwarf

From : S K Ghoshal, Indian Institute of Science, Bangalore

Let N=1. Write a computer program that initializes a floating point number to 1.0. Then it multiplies it N times by 0.5. Then it multiplies it N times by 2.0. Then it prints the number. You will see it print 1.0 again. Increase N. At one point (if your computer is using IEEE 754 single precision arithmetic, it will come at N=150), you will see it print 0.0. You will realize that there is a minimum non-zero floating point number in every computer (some folks call it *dwarf*) and the computer cannot handle numbers between *dwarf* and 0.0. They are forcibly made 0.0 by the floating point unit of your computer. Can you analytically work out the value of *dwarf*? Find out more by running the program given below and reading David Goldberg's article "What Every Computer Scientist should know about Floating Point Arithmetic" which appeared in ACM Computing Surveys, March 1991, pp.5-48.

C program to explore single-precision FP arithmetic.

```
typedef struct {unsigned int sign:1; unsigned int expo:8;
                unsigned int mant:23;} floa_t;
   typedef union {floa_t ipart; float fpart;} myreal_t;
   main () {
     int i = 1; volatile myreal_t r; r.fpart = 1.0;
     printf("See the bit patterns of floating point numbers/n");
     while (r.fpart! =0.0) {
     printf ("f=%e, Iter=%d, Sign=%x, Expo=%x, Mant=%x \n",
     r.fpart, i, r.ipart.sign, r.ipart.expo, r.ipart.mant);
     r.fpart = r.fpart * 0.5; i++;}}
```

4 Customers in Book Exhibition

From : Bhaskar Bagchi, Indian Statistical Institute, Bangalore

Discussion of question raised in *Resonance*, Vol 1, No 4.

In the book exhibition, for any two distinct books on display there was a unique customer who wanted both books, while no customer wanted all the books. In the April issue of ***Resonance***, you were asked to find out if there were more books or more customers. The answer is that there must have been at least as many customers as there were books. Don't be disappointed if you

could not do this (and more power to you if you could!); after all, this is a moderately famous theorem of P Erdös and N G DeBruijn.

To prove this theorem, let's first set up some notations. Let υ and b denote the number of books and of customers, respectively. For $1 \leq i \leq \upsilon$ let r_i denote the number of customers who want the ith book. For $1 \leq j \leq b$, let k_j denote the number of books wanted by the jth customer. We have to show that $b \geq \upsilon$. This is quite easy if $r_i = b$ for some i. So, we may assume $r_i < b$ for all i. By turning away all customers who want only one book or none, we may also assume that $k_j > 1$ for all j. From our assumptions, it is now easy to see that we have

$$\left.\begin{array}{l} 1 < r_i < b \text{ for } 1 \leq i \leq \upsilon \\ 1 < k_j < \upsilon \text{ for } 1 \leq j \leq b \end{array}\right\} \qquad (1$$

First proof (J H Conway) : Begin by noting that if i, j are such that the jth customer does not want the ith book then $r_i \geq k_j$. Indeed, for each of the k_j books wanted by j, there is a customer who wants this book as well as the book i. Thus we have k_j distinct customers (at least) who want i. If possible, let us suppose $b < \upsilon$. Together with $k_j \leq r_i$ this yields $bk_j < \upsilon r_i$ and hence $k_j(b - r_i) < r_i(\upsilon - k_j)$. Thus we have

$$\frac{k_j}{\upsilon - k_j} < \frac{r_i}{b - r_i} \qquad (2)$$

whenever customer j does not want the book i. (Here we have used (1).) Now form two $\upsilon \times b$ arrays A and B as follows. If the customer j wants the book i then place a zero in the intersection of the ith row and jth column of A as well as of B. In the contrary case, put $\frac{k_j}{v - k_j}$ in this position of A and put $\frac{r_i}{b - r_i}$ in B. Then for $1 \leq j \leq b$, the jth column of A has $\upsilon - k_j$ non-zero entries, each equal to $\frac{k_j}{v - k_j}$, so the sum of the entries of A in this column is k_j. Thus the sum of all the entries of A is $\sum_{j=1}^{b} k_j$, which is the number of zero entries of A. Similarly, the sum of all entries of B equals the number of zero entries of B. But, by our construction, A and B have zeros in precisely the same positions. Thus, sum (A)

= sum (B). But this is impossible since by (2), each entry of A is strictly less than the corresponding entry of B, unless both entries are zero.

This contradiction shows that we must have been mistaken in our assumption $b<\upsilon$.

Second proof (R C Bose) : Form the $\upsilon \times b$ matrix N whose (i, j) entry is 1 if customer j wants the book i, and 0 otherwise. Then the information we have translates into the language of matrix multiplication as

$$NN' = D+J \tag{3}$$

where N' denotes the transpose of N, D is the $\upsilon \times \upsilon$ diagonal matrix whose diagonal entries are r_i -1, $1 \leq i \leq \upsilon$, and J is the $\upsilon \times \upsilon$ matrix with all elements equal to 1. Now, J is a non-negative definite matrix and (because of (1)) D is positive definite. Therefore, by (3), NN' is positive definite, and in particular, NN' is non-singular. So the rank of NN' is υ. But N has the same rank as NN'. Thus some υ of the b columns of N are linearly independent. But, of course, this requires $\upsilon \leq b$. Alternatively, the reader can verify that $D+\mathcal{J}$ is non-singular (and hence reach the same conclusion) by establishing the identity

$$\det(x_0\mathcal{J} + diag(x_1, \ldots, x_v)) = (\sum_{i=0}^{v} \frac{1}{x_i})(\prod_{i=0}^{v} x_i)$$

Third proof (V Pati): This is a variation of the second proof. Again, one shows that the rank of N is υ, but this time by directly verifying that the υ rows $\underline{y}_i$, $1 \leq i \leq \upsilon$ of N are linearly independent. Suppose, on the contrary, that we have a linear dependence

$$\sum_{i=1}^{\upsilon} c_i \underline{y_i} = 0 \tag{4}$$

where the real numbers c_i are not all zero. Letting $\langle \cdot, \cdot \rangle$ denote the usual inner product on R^b, equation (3) may be rephrased as

$$< \underline{y}_i , \underline{y}_j > = \begin{cases} 1 & \text{if } i \neq j \\ r_i & \text{if } i = j \end{cases}$$

for $1 \leq i, j \leq \upsilon$. Therefore taking the inner product of the two sides of (4) with each $\underline{y}_j$, we get $c_j r_j + c - c_j = 0$ or $c_j = -\frac{c}{r_j - 1}$ for $1 \leq j \leq \upsilon$, where $c = \sum_{i=1}^{\upsilon} c_i$. Summing over j, we get $c(1 + \sum_{j=1}^{\upsilon} \frac{1}{r_j - 1}) = 0$. Since the expression within the brackets is strictly positive, we get $c = 0$. Plugging this back into the formula for c_j, we get $c_j = 0$ for $1 \leq j \leq \upsilon$. This is the contradiction we needed to complete the proof. (In disguise, this is yet another proof that $D + J$ is non-singular.)

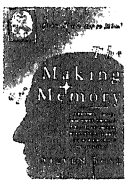
Tail-piece : This result may be easily generalised to obtain the following theorem by H J Ryser and D R Woodall : Suppose there is a fixed constant $\lambda \geq 1$, any two of the books are demanded by exactly λ customers, while again no customer wants all the books. Then, letting υ, b be as before, we still have $b \geq \upsilon$. In fact, the second (or third) proof given above goes through for general λ. But the beautiful elementary proof of Conway does not seem to generalise: we do not have the right analogue of the inequality (2). May be some clever reader can find a way around this difficulty?

How about the case of equality : $b = \upsilon$? Here many difficult unsolved problems crop up (and these are significant mathematical problems, not merely puzzles). For instance, when $\lambda=1$ and $b=\upsilon$ then it can easily be seen that (excepting in a trivial situation) $\upsilon=n^2+n+1$ for some positive integer n. It is widely believed, though nobody has a proof, that n must be a power of a prime! Again, take a general λ and $b=\upsilon$, and consider the two statements: (a) there are two constants k_1, k_2 such that each customer wants either k_1 or k_2 books, (b) there are two constants r_1, r_2 such that each book is wanted by r_1 or r_2 customers. One of these two statements is a theorem, while the other is an open problem! Can the reader figure out which is which? When λ is a prime, both statements are correct - this is a theorem by N M Singhi and S S Shrikhande.

Memory as a Life

Walking Down Memory Lanes

S Krishnaswamy



The Making of Memory
From Molecules to Mind
Steven Rose
Anchor Books Doubleday.
New York. 1992
pp 355 Rs 430
ISBN 0-385-47121-1

Often the blurbs on book jackets are inserted by eager and hungry publishers with both eyes on sales. This book belongs to that rare and endangered species where the back cover tells you what to expect up front. "Are there molecules of memory? Can we understand the brain best as a computer? What is locked into the interactions of the brain cells and the molecules composing them, that carries the memories that make each person unique?" Steven Rose gives you your money's worth of answers (plus many tit-bits to laugh at and/or thoughtfully chew on). In *The Making of Memory*, Rose retraces the road he and his fellow researchers have followed to a new understanding of the cellular mechanisms of memory and learning. Combining a richly detailed account of scientists at work with a highly readable explanation of cutting-edge neuroscience, the book offers fascinating new insights into the links between brain and mind."

The book is a must for libraries and a personal treasure to have. In a casual but lucid style Rose explains how the study of memory is likely to provide the link between the brain and the mind. In the process he places our science and its symbiotic relationship with society in perspective. He describes how every culture and period in history has offered its own analogy for memory. Take for instance our tendency to picturise the brain in terms of computers. He shows how none of these analogies captures the richness of real memory whose understanding lies in the biology of the brain itself, the dynamics of the structural, chemical and electrical interactions between its molecules and cells, but which cannot be reduced *merely* to these.

In a casual but lucid style Rose explains how the study of memory is likely to provide the link between the brain and the mind.

Rose takes you through the day-to-day routine of a scientist, in particular that of a scientist studying memory using chicks, which is what Rose himself does. Full of spirit and irreverence, the exercise, and much of the book - for example his description of conferences and writing research papers - helps to bring science back to the human being outside, or borrowing from R K Laxman's cartoons, to 'The Common Man'. Steven Rose chooses appropriate words in his writing and so with his philosophical permission I reproduce, with a bit of editing, his words which I think carry the spirit of the book. To get to the science in the book I sug-

gest that you buy the book or–if you can–get somebody else to buy the book for you, and read it.

"Although this book is primarily about individual memories and their biology, in writing it I have found myself continually confronted with the phenomena of collective memory, and you will find them forming a subtext through many chapters... This book has a further purpose, integral to every chapter. Each act we make within our laboratories is dependent for its meaning on the cultural and ideological assumptions of the world which surrounds the lab, just as the lab would not exist without the technological underpinnings of machinery, chemicals, power and money which are omitted from the conventional accounts of science. And no act within the lab is a mere passive contemplation of nature; the products of our work themselves generate new technologies just as certainly as they generate new understandings... that can potentially transform the quality of our lives - at least for those living in relative abundance in technologically advanced societies - from cradle to grave... I write this book at a critical juncture. Simplest would be to ignore the philosophical and social issues and to tell a straight story... But I want to do more than that; I want to describe what it feels like to be a neuroscientist, to design experiments, to train animals, to study their biology, to build - and reject - theories, to demystify the workings of my sort of science. I am not writing this as an observer from outside, nor yet as a textbook or state-of-the-art review. I want to share with you, as the reader, something of the excitement and frustrations of my life in the lab over the past twenty years. And in doing so, I want also to go some way towards bridging the gap in my own life, between the would-be objective observer in the laboratory and the subjective human outside. Bridging this gap, I maintain, is essential if we are to move beyond our fragmented culture towards a new synthesis which transcends both the ruthless reductionism of a science indifferent to human values and a subjectivism for which truth is but one story amongst many of equal worth." Not mere words these, as seen in the pages of the book where his passion for communication carries you along.

I want to describe what it feels like to be a neuroscientist, to design experiments, to train animals, to study their biology, to build - and reject - theories, to demystify the workings of my sort of science.

This book was intended for the general public and the practitioners of science; it fits the bill perfectly and enjoyably - from type font and quality of illustrations to the way molecules, neurons, experiments, politics and scientific theories are handled. Rose describes one of his experiments on

chicks, which fits in with the theories of memories, describes his subjective memories and personal development as a neuroscientist. He shows how biochemistry branched into neurosciences, and what we can learn about human memory by studying those disorders of memory caused by diseases or accidents - and the limitations of this approach. Subsequently one learns why people erroneously believed that there were specific 'memory molecules' which could be transferred along with the memories they carried, the reasons for this error and the fallacious experiments on which it was based. He also describes how scientists, like him, learn to design experiments to avoid such errors. Then one learns how different organisms from sea slugs and sea horses to day old chicks are used in modern memory research and in the process we learn how molecules are actually involved in memory formation, although not as thought earlier. Take, for example, communication at the pre - and post - synaptic junctions of neurons. During memory formation, transmitter molecules ('glutamate') released from the pre-synaptic side interact with the receptor molecules on the post-synaptic side, resulting in addition of phosphate groups to some proteins in the membrane and the triggering of calcium entry. The calcium provides a signal to the nucleus for the activation of certain genes and synthesis of protein and glycoprotein molecules. These are transported and inserted into the membrane at the junction thereby changing it's size and shape. Later Rose goes on to show how the molecular aspect is merely one level at which we learn about memory. Memory is a property of the entire brain, the whole organism, and in the case of humans - also of recorded social thinking.

Finally, borrowing from Rose his words used in a slightly different context best epitomises the usefulness of this book. "Let me revert to a more domestic example. Understanding the biochemistry of cooking and the physiology of digestion will surely never reduce the enjoyment of the meal to 'mere' biology - but it undoubtedly enriches and improves both our cooking and our eating."

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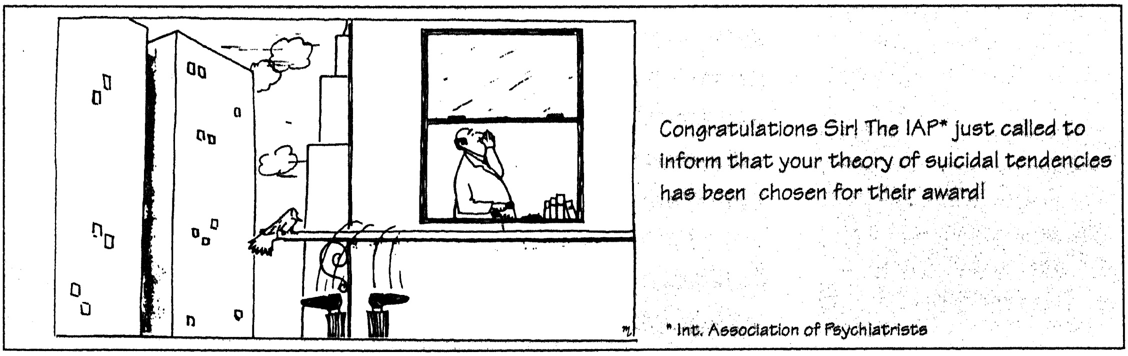

Science - its Philosophy and Spirit

Professor Hermann Bondi

Hermann Bondi is a fellow of Churchhill College, Cambridge. He was a Raman Professor of the Indian Academy of Sciences, Bangalore. Bondi (with Gold and Hoyle) is well known for his Steady State Theory of the Universe, for establishing the reality of gravitational radiation in full General Reality, for evolving the clearest way of teaching Special Relativity etc. His early, concise book on Cosmology was a classic. After the sixties, Bondi took up administrative challenges and was Chairperson of many committes that gave direction to science in the UK and Europe. He is very interested in the wider implications of science and the scientific outlook as testified by his membership in the Humanist Association and the Science Policy Foundation.

I would like to start with some remarks on the philosophy of science. Perhaps this is a slightly dry subject, but there are certain conclusions that I think are of general relevance.

I am very much a follower of Karl Popper when he says that the chief criterion, the demarcation between science and other human pursuits, is that in science you can make statements that are capable of being disproved empirically by observations or experiments.

Why this pathological - so it seems - concentration on disproof? Usually a theory makes a general statement but as Popper insists, you can't infer a general statement from any number of instances of observation. To take my favourite stupid example, if you observe as Newton did that apples drop, you cannot logically infer from this that any apple, when you release it, will drop; because this theoretical statement or law applies to all apples - past, present and future. You certainly don't know how future apples will behave!

It could be that fifty years from now, somebody breeds an apple so light that it rises when you release it, and that would disprove this theory. You cannot make conclusions from the particular to the general, but you can always shoot down a general statement by the particular. So we know that the history of science is strewn with disproved theories. But you cannot perform all the experiments that a theory can possibly talk about; therefore you cannot prove it.

It is only if you can be wrong, that you say anything worth saying. I like to refer to weather forecasts in England, where

one is a little less sure than here. If I tell you tomorrow will be either warm or cold, sunny or cloudy, windy or still, wet or dry, you won't be able to disprove me whatever weather comes tomorrow. But I haven't told you anything. I tell you something valuable only if I may turn out to be wrong. And this ability to be wrong is the hallmark of a scientist.

This article is a slightly edited version of a lecture delivered to the Indian Academy of Sciences.

Implicit in this is the idea that future tests of theories will be more demanding than present tests, will be more precise, will be more searching. Our experimental apparatus is of course always provided by the technology of the day, which we may push on a little for the purposes of our experiment. Popper's definition of science makes particularly good sense if we assume that technology progresses. The progress of technology generates the progress of science, but of course technology may make use of science to incorporate it into new developments.

You cannot make conclusions from the particular to the general, but you can always shoot down a general statement by the particular.

My favourite example in this 'leap frogging' of science and technology occurred when I was once puzzled by why these great discoveries in fundamental physics - the existence of the electron, the existence of ions, x- rays and so on - were all made in the last quarter of the last century. Why just then? Why not twenty five years earlier or later? When I looked at this, I found that earlier the problem had been the maintenance of a vacuum in highly evacuated vessels. The great progress that was made to enable the vacuum to be reliably maintained so that you could carry out intricate experiments, depended on two things. One was the machining of brass pistons, a very humdrum technology but one which had not been developed sufficiently earlier to make good vacuum pumps.

Secondly, however good your pumping equipment, you are bound to find leaks. How do you plug a leak in a vacuum equipment? Of course the ideal material was sealing wax, and sealing wax is beautifully airtight and is very suitable in any place where its rigidity doesn't matter. But of course you have a vibrating pump and your experimental equipment is

This ability to be wrong is the hallmark of a scientist.

supposed to be nice and steady (so a rigid coupling to the pump was undesirable). A material then became available that could be used to plug leaks and it was plasticine. And so most of modern physics is therefore based on the availability of plasticine! Just because it is a child's toy doesn't rule it out, it has of course the disadvantage of a significant vapour pressure. But in small quantities, this was very good for vibrating leaks and they could be plugged with it.

Now it was this invention that led to X-rays. This was a great discovery of Rontgens' just over a hundred years ago, and very soon it was realised that they would be very useful medically. And so the cry arose for X- ray machines and a new technology arose to make them. They began to be quite good, but of course at first the dangers of X-rays weren't realised and the earlier radiologists all had troubles. Once these were appreciated, the technology of X-ray machines was perfected and they were made safe, reliable and responsive in every way.

Technological advances were the chief tools that led to the origin of molecular biology - the analysis of biological materials. And as you know this great scientific advance led to modern bio-technology.

These technological advances were the chief tools that led to the origin of molecular biology - the analysis of biological materials. And as you know this great scientific advance led to modern bio-technology. So you see in this mutual interaction, you can't say one comes first and the other is secondary. They each rely on the other and as Popper says somewhere (I remember this distinctly but I have never been able to find the reference again), it all reminds me of a person walking in a swamp. First he pulls up one leg painfully and puts it forward and then the other leg, one is labelled science and the other is labelled technology. And they are as dependent on each other as this suggests.

There are fields of science where the application of the Popperian criteria has caused a certain amount of resistance and soul searching. That is in fields which you might call historical. The most famous and nearest of these fields is the question of the origin of the solar system. And let me say here

by the way that one of the points about Newton that excites my admiration particularly is this. A scientist not only has to define a problem, he has to think which parts of the problem are solvable. Peter Medawar once called science the art of the solvable. Now, Newton was given one heap of data by Tycho and Kepler to form his theory, and he divided this amorphous heap into two with a sharp knife. On one side he put the questions: given the masses, positions, and velocities of the bodies of the solar system on one day, can you predict where they will be in future, or hindcast where they were in the past? And he solved this problem for all practical purposes completely. The other problem was: why do they have these masses, positions and velocities? It is basically the problem of the origin of the solar system, which he left severely alone and rightly so. Some three hundred years later we are not much further forward.

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Questions like the origin of the solar system, the origin of the earth and of life, geology and so many other things, are basically historical questions. How can we apply Popper's criteria to them? Well, it is easier to apply Popperian criteria to repeatable experiments, but nevertheless nothing by Popper suggests that the inferences that you test empirically need to be very direct inferences. So we can look at a theory of the origin of the solar system, see what results it would predict concerning fossils, and then see whether those fossils can be found. And the history of the theory of the origin of the solar system contains many suggestions that have actively been disproved; and so Popperian criteria can be applied just as well to historical as to repeatable items.

Even in cosmology, when we formulated the steady state theory in 1948 and people told me, "Isn't the universe a changing place?", I said "If it was different in the past from what it is now, show me some fossils." And no such fossils were known in the 40s and 50s. We now have a number of fossils, some slightly debatable and some very firm, we have

The importance of linking the empirical and the theoretical depends of course on good communication in science.

the abundance of helium and other light isotopes, we have the background radiation, and these fossils are known now. But none of those fossils existed at that time. Fossils are as good a test as anything of what went on in the past. And just because something is historical, does not rule out the Popperian criteria.

The importance of linking the empirical and the theoretical depends of course on good communication in science. And in one sense we accept completely that nothing in science is considered done unless it is published. We don't add to that the condition that it should be capable of being understood. And with some papers this is not the case. I always feel that the one outstanding duty of a referee is to assume that one is not the stupidest person to whom this paper ever goes. If one can't understand it then probably other people won't be able to understand it either.

Even if I repeat myself here, one of my stories is that in the 50s, I was responsible for organising the meetings of the Royal Astronomical Society. Whenever we had a young author come to give a paper, I always took that person aside and said, "Look, you are going to address some of the most distinguished astronomers in the world, please talk to them as though they were children twelve years old." Very few of them took my advice. A few did, whether they thought the same before or not. So many of them had a wholly exaggerated idea of the absorbing capability of famous persons and if they talked as they intended to, then usually they got a very nice thank you at the end of their talk and no discussions at all because nobody had understood a word of it. If they talked to us as though we were children twelve years old, they got a marvellous discussion going.

Whenever we had a young author come to give a paper, I always took that person aside and said, "Look, you are going to address some of the most distinguished astronomers in the world, please talk to them as though they were children twelve years old".

How one learns things of course is to a slight extent personal. In other words one can look at the various means of learning. There is the text - the printed word. I think it is a pretty good method, it is there, it is permanent, but it is distinctly

impersonal. And I always prefer to read the papers of people I know; when I read the words and listen to this rise and fall of their voices, it becomes much clearer to me. In a lecture you at least have the rise and fall of the voice, but if it is a big lecture room, and there is no discussion, you can't shout "Hey I don't understand a word of this". You may be left behind very early in the talk.

Peter Medawar once gave a talk under the title 'Is the Scientific Paper a Fraud?' and he answered with a resounding 'Yes'!

To digress for a moment, our BBC used to be very proud of its radio broadcasts called the *Third Programme* - in which I was occasionally asked to speak. Well, on one occasion, they asked me to talk a week or so hence, and I asked: "What standard should I aim for?" Then they said, "Well, when you go home tonight, switch on the radio and that will be the first talk in the series. It hits exactly the right level". Well, I switched it on, it was on a biological subject. I followed the first few sentences. And then I was left totally behind. I hope I did not talk like that afterwards. But all one sided communications have this difficulty that you can't shout, "I don't understand". Whereas a seminar, where you can interrupt, is much better.

I must confess that I think the best method of science communication is to stand in a bar with a glass in one's hand. Because, then people are prepared to talk not only about their successes but also about their failures - which are usually vastly more informative than their successes. Without some inhibitions removed, one doesn't talk about them.

I think the best method of science communication is to stand in a bar with a glass in one's hand. Because, then people are prepared to talk not only about their successes but also about their failures - which are usually vastly more informative than their successes.

And indeed the printed word has other difficulties; we write in a very formalised style. Peter Medawar whom I had mentioned before once gave a talk under the title 'Is the Scientific Paper a Fraud?' and he answered with a resounding 'Yes'! My way of putting this is, when we work on a problem for three years and get absolutely nowhere, the final failure makes us think there might be an adjacent problem on which we can make some impression. And we do so and we publish it as though we had only worked on the second problem, and

A large number of people think of our subject as dull and unadventurous and erect the fiction of the objective passionless scientist. Well, I have never met a scientist who is any good, who is either objective or free of passions.

as though we had solved it in an afternoon. The difficulties of it are nowhere mentioned in the papers. If a nonscientist is able to read some of these papers, they get a wholly wrong idea of how we spend our time, and they think most of the time is spent idly.

But what I want to concentrate on this afternoon is the spirit of science, that we are always very adventurous, and we try things out because everything is liable to disproof because we are all fallible anyway; because of that we can be daring and adventurous. Yet when we teach science at high school or even at the under graduate level we don't teach it in that manner at all. We teach in order to cram as much science into people as possible, we teach only those parts which are allegedly certain and well established, and we expect that for every question there is one right answer and all the others are wrong. Now that is the image we convey of science, and I think it is a pretty wrong and false image.

I am speaking of course from the UK experience but I feel it is much the same elsewhere. This has many difficulties. First it estranges the large number of people who do not become scientists. They think of our subject as dull and unadventurous and erect the fiction of the objective passionless scientist. Well, I have never met a scientist who is any good, who is either objective or free of passions. Of course being deflected by one's interests, being deflected by one's prejudices does not matter in science, because if you talk nonsense or say something that can be disproved, this will soon happen to you. If you are an experimenter, others will repeat your experiments and if they come out wrong you are in trouble. If you talk nonsense as a theorist, people will very soon disprove you experimentally.

The way science is presented relatively few adventurous souls will go into this subject.

And so, it is not that the individual is without passion, or is objective. It is that the whole apparatus is self correcting. I don't think we convey this very well at school and even in

early tertiary education. This has disadvantages both for those parts of the population, the large part, who do not become scientists; but particularly I think for people's career choices because the way science is presented relatively few adventurous souls will go into this subject. If we find somebody like that then it is quite likely inspite of, and not because of, the science teaching they received. It is true that there are inspiring teachers everywhere and you may be lucky; but of course the most inspiring teacher is at the mercy of a relentless syllabus and his students want not only to be inspired, they also want to pass their exams. That is the sad thing.

Once, when I was concerned with a group of colleagues in devising a syllabus, one colleague said that the aim of a good syllabus is to interfere with education as little as possible.

Once, when I was concerned with a group of colleagues in devising a syllabus, one colleague said that the aim of a good syllabus is to interfere with education as little as possible. And I think it is a very wise request but very hard to fulfil. Indeed the prospectus we hold out to people to attract them to our subject is so peculiar that I feel if we were in business and issued such a prospectus for the shares in our company we would be in trouble with the law. We would be accused of selling shares fraudulently. This has many disadvantages in the matter of recruitment. Certainly many people who come into science, later find it a little disappointing. The way we are regarded by the rest of the population is also affected.

To come back to an earlier point, our adventurous nature is also very beneficial to technology. When it comes to instruments we want the very best that could possibly be produced. If that has a risk of failure, of not working at all, we are quite prepared to take that risk. In the development of technology, to have a risk-taking customer is very important for the advance of technology, as is shown for example in space technology.

You are not proud if you have a failure, but if you never have a failure then you are far too conservative.

You are not proud if you have a failure, but if you never have a failure then you are far too conservative. Perhaps one of my

stories will help. When I ran the European Space Research Organisation, I did an enormous amount of flying to the various establishments and to various governments. And I found that the drivers always brought me to the airport much too soon. Now this seemed to me a misuse of my time and I laid down the rule of much shorter periods which of course carried a certain risk. But certainly within Europe where there is a plane almost every two hours or so, the worst penalty would be not so very bad, in any case better than hanging around in airports eternally. When the new system was functioning and I missed my first plane, the colleague who was with me said "now you really know you have raised the efficiency of the organisation". While it is very important to strive for no failures, you should not be so cautious that you never have any, because you don't know how far you are from the edge if you never fall off at all. It would be interesting to compile a philosophy for technology saying how many failures you should have. Too few failures is certainly very conservative. And some space engineering is exceedingly conservative. I remember, when the space age was still fairly young, suggesting to a space engineer that something or the other should be flown, and he said, "No, no, we can't put that in space; it has never been in space before." So conservatism has a disadvantage.

While it is very important to strive for no failures, you should not be so cautious that you never have any, because you don't know how far you are from the edge if you never fall off at all.

I would much favour different ways of teaching science, through much more history and the philosophy of science. If you do this in a given number of teaching hours, the total volume you are able to convey will be much reduced. And people will know less of the results of science, but I trust, a lot more of its spirit. Let me give you an example of what I would like to see done in science.

We teach everybody that the earth goes around the sun, but we don't do much to tell them how the concept arose and how it was tested. And indeed there is an interesting bit of

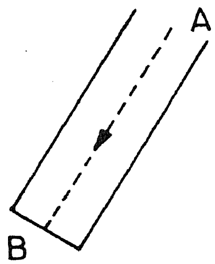
scientific history here. By the late 17th century, every scientist accepted the Copernican system. But how was it to be tested? The most obvious test was to look for stellar parallax, look at the way near stars move relative to the backgound of distant stars as the earth moves in its orbit. And indeed an enormous effort began to measure stellar parallax which would not only test the Copernican picture, but would of course tell us something about the distance of the near stars. And this proved to be an enormously long and difficult enterprise.

First one didn't know which stars were the near ones. Though the brightness was some guide, it wasn't a particularly good guide. Secondly, the accuracy of instrumentation in the days before photography to show that the picture six months later was indeed a little different from the picture before, was not available. Third, the distance of the nearest stars was not known and so one was not even aware of the magnitude of the effect one was chasing. In fact, the stars are so far, that with the nearest star the parallax is less than a second of arc, and that is not very much as you know so very well. So after dozens of claims that couldn't be substantiated, the first unambiguous parallax was only measured in 1838 by Bessel, 150 years or so after the search began. But much sooner on the way a remarkable man - James Bradley - had discovered a wholly different and unexpected effect. Whereas most people with parallax tried to measure the relative angles between stars that were not too far apart in the sky, he thought he could better measure large angles. And he found in 1725, well over a hundred years before the first parallax was established, a movement that not only was relatively large but that was at a right angle to the movement that he expected due to parallax.

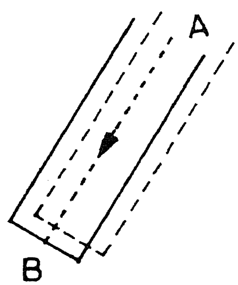
I would much favour different ways of teaching science, through much more history and the philosophy of science.

If I rightly remember my history, in about a week he had puzzled out what the phenomenon was - what we now call the aberration of starlight, which is due, not to the earth changing its position, but to the earth changing its velocity in its orbit

Aberration



A 'fixed' telescope



A moving scope

Notice that because of the motion during the time taken by light to travel along the telescope, the light arrives at a different point. Hence a different direction is infered for the star.

around the sun. This change in the apparent direction which is about 15 times as large as the parallax of the nearest star was the first unambiguous test of the Copernican system. Not only don't we teach this in high school, we don't even teach it to undergraduates. Yet it is a very good story. Not only that when you are a good scientist you are puzzled by the unexpected turning up, but that the unexpected may be remarkably fruitful as it has been in this case. We can also admire our predecessors for being able to measure such small angles with the instrumentation available in the day.

To make another remark about this, the earth being an inner planet has of course a relatively small orbit and moves relatively fast. Had civilisation developed not on the earth but on Jupiter, parallax angles would have been much larger, stellar aberration would have been much smaller and parallax would have been discovered before aberration! Indeed, I sometimes think of what the development of science would have been like had the solar system only consisted of the sun and the earth. Conditions for the development of life would have been almost identical, yet the whole field of astronomy, of observing the planets would have passed us by; and I suspect science in such a place would not have started with astronomy. There would have been no material for a Tycho, for a Kepler, for a Newton, for a Galileo to have worked on. It is a very fortunate circumstance that the solar system is so replete with bodies.

Indeed you can extend it even further. As a theoretical man, I know that however strange the object I think of, somewhere in the universe you will find something like that. As I like to put it, the universe is an extraordinarily well stocked laboratory. We should try and find the oddest things - sometimes theories, more often observations, that tell us something which we find difficult to account for.

Of course one of the most tricky areas is not in astronomy, but in the life sciences, where the greatest challenge is the origin

of life. I don't want to talk about it, but I do want to say that this has puzzled people for generations. But occasionally one meets somebody in biochemistry who thinks it will be only twenty years or so before we can produce life in the laboratory. Let me tell here a story which was current in the UK about the giving of grants, according to which God applied to the Medical Research Council for a grant to study the origin of life. This application was rejected for three reasons. First, no evidence was submitted that the applicant had worked in the field since long ago. Secondly, others had been unable to repeat this experiment. The third and most serious, he only published his work in a book and not in a refereed journal. This is one of our problems with the science industry; the refereed journal holds such a sway that we are in great difficulties. Yet, I must say that refereeing has the great advantage of making things at least intelligible.

Now if we taught science through its history and through its disappointments, failures and the like, I think we would excite the young much more.

Now if we taught science through its history and through its disappointments, failures and the like, I think we would excite the young much more. Let me give an example of relatively recent times, the beginning of the space age. As is well known, the first discovery was the Van Allen belts of charged particles in roughly equatorial latitudes. Now for several decades people had been working out what the aurora was like, and what caused it. Through very ingenious application of the earliest forms of electromagnetic and Lorentz theory, they could show that particles would penetrate nearer the earth in the polar regions near the magnetic poles before they would be reflected back by the increasing magnetic field. There would be only a very small selection of particles that would get that far down to the area where the aurora was caused. You imagine the particles in space to be in general motion; it would then be only those whose velocity vector made a remarkably small angle with the lines of force that would come down to be able to generate the aurora.

Adventurousness is often missing in science. I can blame myself for having missed something in the forties. One should always be daring.

So it needed nothing but courage to say there must be a much larger assembly of such particles above equatorial regions. But nobody dared to say so and it required Van Allen's experiments to discover these. Then the theoreticians said, "Yes, of course we knew that all along, we just didn't dare to say so". May I say that their not saying so had the effect that even Van Allen's counters were overloaded. He hadn't counted on there being so strong a radiation belt as was found to be the case.

And so adventurousness is often missing in science. I can blame myself for having missed something in the forties. Going back a little bit, when Eddington developed the theory of the structure of stars by his brilliant efforts described in his book *'Internal Constitution of Stars'*, he found by his methods that the central temperature was around 40 million degrees. He found much the same temperature for all stars. Now the nuclear physicists of the day told him that what everybody thought must be the source of stellar energy - thermonuclear processes - could not possibly go on at temperatures as low as that. And he is reported to have said that if the centre of the sun is not hot enough for the nuclear physicists, they should go to a much hotter place.

Much more has been missed out through fear of being ridiculed than through making mistakes, because the system corrects itself for mistakes but not for areas where courage fails.

As a matter of fact, as the theory advanced, the numbers came down and there was a temporary agreement between the stellar structure analysts and the nuclear cross sections of the day in the mid 40s, at about 20 million degrees. A few years later, I did an analysis and found that this temperature should come down to 14 million degrees, but hesitated to publish it. Three years later Fowler, Lauritsen and their colleagues found the nuclear cross sections were all wrong and 14 million degrees was the right temperature! One should always be daring. Much more has been missed out through fear of being ridiculed than through making mistakes, because the system corrects itself for mistakes but not for areas where courage fails.

How much of this do we convey to the general public? To fake an experiment - that indeed is a dreadful thing to do, but with a bit of luck it won't last very long because others will check and expose you. And in recent times, all of you will remember the hoo-ha about cold fusion and how soon that was exposed. But if you do something and if you propose something and it makes people do other things, to check it by sophisticated methods, theoretical or experimental, then you have stimulated something. If your work or ideas are disproved no harm is done. The cart of science has moved forward, though not perhaps in the direction which you hoped it would move, but you have been influential in doing something.

If you propose something and it makes people do other things, then you have stimulated something. If your work or ideas are disproved no harm is done.

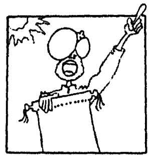
To be original is the greatest praise you can confer on a scientist, and to be dull is the worst. But how much of that do we convey? Let me make a plea for trying to make science exciting even if we have to accept that people come and start their serious studies knowing less at that stage. We have to convey the spirit of science with its inevitable going forward and backward. We have to teach the story of phlogiston - you remember the brilliant idea that there was a substance which was the substance of burning - before Lavoisier discovered that burning is oxidation; and the marvellous way in which people tried to save that theory against evidence until finally it was disproved.

Telling stories like that would be very useful and might perhaps lead to a less cynical outlook than Max Planck displayed at one stage when he said that old theories are not disproved, it is just that their supporters die out. This brings me to my last point. There is nothing as important in science as bringing in young people because only that way can we have a fresh outlook, a critical outlook, the way of having new ideas that are so essential. And don't overawe them: "Authorities are always wrong" is a very good principle.

Let me make a plea for trying to make science exciting. We have to convey the spirit of science with its inevitable going forward and backward.

Thank you.

Information and Announcement



Silver Jubilee Meetings of the Ethological Society of India and National Symposium on Behaviour December 28-30, 1996

The silver jublee meetings of the Ethological Society of India and National Symposium on Behaviour will be held during 28-30 December 1996 at the School of Life Science, Pandit Ravishankar Shulka University, Raipur 492 010. For further information please contact Dr. A K Pati, organising secretary at the above address.
Telephone: (91-771) 26031 (O) (91-771) 537189 (R); Fax: 91-771-534996.

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Acknowledgements

Resonance gratefully acknowledges the help received from the following individuals:
L Geetha, Sumana Rao and V Pati.

Erwin Bünning was born in Hamburg on 23 January 1906 as the son of the teacher Heinrich Bünning. He studied biology, chemistry, physics and philosophy at the universities of Göttingen and Berlin from October 1925 to July 1928 and obtained his D Phil degree from Berlin University in 1929.

He worked first as lecturer in Frankfurt University, University of Utrecht and in Königsberg University and later as reader (Dozent) *at the university kof Strasbourg. He became a full professor at the end of the Second World War in 1945 at the University of Cologne and accepted the Wilhelm Pfeffer Chair at the University of Tübingen in 1946, where he stayed for the rest of his life.*

Bünning had all the character traits of the classical Ordinarius Professor of his times, complete with the reputation of not being easily accessible. He was prophetic about several recent developments in research and teaching in biology. He preferred to be called a biologist rather than a botanist. In this and other matters he was greatly influenced by the life and work of Whilhelm Pfeffer (1845-1920). Bünning has written an eminently engaging biography of his role model Pfeffer.

Bünning published about 260 papers in various fields of plant physiology and general biology, wrote the first monograph on the subject of biological rhythms, gave the first detailed account of the history of chronobiology in the form of 'The Chairman's Address' at the first Cold Spring Harbor Symposium on Biological Clocks (1960) and a well known text book on plant physiology. Bünning's entirely original idea that 'circadian rhythms act as yardsticks' in measuring seasons was first spelled out in his paper of 1936. This paper ('Bünning E Die endonome Tagesrhythmik als Grundlage der photoperiodischen Reaktion', Ber Deut. Bot. Ges., 1936, 54, 590-607*) became a citation classic of current contents in 1982 and the idea conveyed in it is today known as* Bünning's hypothesis. *After his retirement in 1971 the universities of Glasgow (1974), Freiburg (1977), Erlangen (1977) and Göttingen (1986) honored him with doctorates* honoris causa. *He is fellow of seven academies including the US National Academy of Sciences (foreign associate). He was elected honorary fellow of the Indian Academy of Sciences in 1986, which he considered 'a great honor and pleasure'. He died three days after contracting pneumonia in Tübingen on 4th October 1990.*

Erwin Bünning
1906-1990